Circular Infrastructure for a Regenerative Wool Economy: Revitalizing the Italian Sheep Wool Supply Chain in the Mediterranean

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Abstract. To rebuild the wool supply chain in Italy, understand the critical issues, and study the possibilities for its use, we must start from a certain fact: the wool from approximately 6 million sheep, raised more for dairy and meat production than for weaving, is virtually unused. Farmers do not know how to use the 'dirty' wool that has just been sheared and still needs to be washed, due to the lack of washing facilities for small and medium quantities. Some try to store it, while others are forced to dispose of it and pay to do so. The legislation considers dirty wool to be special waste and without the availability of a washing plant, the 'virtuous' cycle of wool management is therefore interrupted. Yet, once washed, dirty wool has important strengths: it has good technical characteristics, and its use would enable a fully traceable supply chain across the country. Sicily alone has 700,000 sheep that produce around 1,330,000 kg of wool. This figure is very important and requires greater scientific attention. The complexity of the issue indicates the need to define a model to resolve certain critical issues and restart the Italian wool sector. The promotion of 100% Italian sheep's wool is the goal that many Italian regions, in synergy with some local communities, are pursuing through various solutions with zero environmental impact.

Keywords: Regenerative wool · Economy · Development

1 Introduction: Wool in the Mediterranean and New Frontiers for Recovery

Since prehistoric times, the Mediterranean basin has always been the cradle of small ruminant farming (sheep and goats). The mild springs are associated with the production of spontaneous and cultivated vegetative biomass, which determines farmers' decisions

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to graze sheep and production milk[1]. The productive aptitudes of sheep are in order: milk, meat, and woo[1]. The mild climate has, therefore, led farmers to focus on milk production, which begins in the early autumn months and ends in summer. As a result, the sheep population is used for milk production, with wool as a secondary by-product.

Wool is the result of shearing, which is carried out at the beginning of summer, allowing the animals to cope with the high summer temperatures without the woolly coat that has accompanied and protected them from the cold during the winter. The main sheep breeds raised in Sicily with a predominantly milk-producing aptitude are defined as open-fleece type, and the wool obtained from their shearing is of lower quality than that obtained from animals specialized in this production. Therefore, its use in yarns has been replaced by wool produced by specialized farms located in the southern hemisphere i.e., Australia, New Zealand, South Africa, and Argentina. The use of wool from dairy farms is beginning to present critical issues related to its use in yarn production, thus becoming a product that can be used and regenerated in other production cycles.

In recent years, which was mainly used for mattress fillings, has ceased to be considered a source of income due to the lack of a market [1, 2]. Wool has become a form of "special waste" because, if left in the open air, it is difficult to decompose and, as such, must be treated, with the costs of disposal borne by farmers. There are still traders who sporadically purchase small batches of dirty wool, but they offer very low prices (€0.10–0.20 per kg). In this context, many who see their hard work devalued tend to bury, abandon, or even burn the wool to save on disposal costs [1]. It is clear how wrong it is for farmers not to dispose of wool properly and for institutions not to adequately compensate them for the costs they incur. The process of purifying dirty wool involves sterilization at over 130 °C, wasting considerable amounts of energy and water, not to mention the problem of purifying the water used in washing. In this tug-of-war between the understandable and the wrong, there is a need to find alternatives, and to do so, initiatives are emerging in Sicily, where grazing land is of particular importance (see Fig. 1).

Section 2 presents the results and best practices already implemented in national and international contexts. The transformation of sheep's wool into materials for use in construction and bio-architecture represents a very promising market sector, with significant positive impacts on the economic, social, and environmental spheres. In Sect. 6, the results of the study suggest that the proposed method could be easily implemented, with significant positive impacts on the landscape and the local area.

1.1 Characteristics of Wool

Wool is a modification of the hair covering of mammals, with the primary function of protecting the animal from adverse weather conditions [1, 2]. It is obtained by shearing the live animal, either by hand or with the aid of mechanical shears, in late spring. The fleece can be divided into an outer layer and an inner layer. The former is coarser, while the latter, known as the undercoat, is finer and more valuable. The fiber structure has a keratin base consisting mainly of 50% carbon, 22–24% oxygen, 7% hydrogen, 17%

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nitrogen, and 3–4% sulfur. The protein that forms the fibrous structure of wool has a common structure that differs between genetic types in length and diameter. The quality of wool differs precisely in this last aspect, from which the product types are derived: - Textile wool, less than 25 MICRON - Croisee wool, between 25 and 30 MICRON - Mattress wool, from 35 to 60 MICRON The quantity and quality of wool produced by an animal vary according to age, sex, environmental conditions and, above all, breed.



Fig. 1. Sicilian sheep grazing, Photo credit: Matteo Bognanno

Wool is no longer considered a source of income due to the absence of a market that uses it and has become a problem for farmers. In the past, it was the most widely used textile fiber, as evidenced by examples from ancient cultures such as the Sumerians, Babylonians, Assyrians, and Chinese. Over the centuries, the breeding of specialized wool breeds has led to wool production being concentrated in New Zealand, Argentina, and Australia.

2 State of the Art: The Sicilian Wool District

The Sicilian wool district was founded in Cammarata (AG) in the heart of the Sicani Mountains and is responsible for promoting wool from Sicilian farms. The aim of the district is to support sheep farms by creating a genuine supply chain. The wool produced

by Sicilian farms is reintroduced into production cycles far removed from animal husbandry, thus improving not only its economic value but also its environmental value, and in this way the beneficiary is none other than the regional territory [1]. The idea behind the district is to transform raw wool into liquid fertilizer through a process of hydrolysis. Applied research and the process of introducing technological innovation are moving along two lines of action. The first concerns the use of wool derivatives in agriculture. Wool, in fact, when subjected to thermal and chemical treatment, can be used as 'biochar' (a stable carbon product derived from by-products, waste, or biomass of plant and/or animal origin), but also as a soil conditioner for sustainable agriculture. The starting point for the implementation of the hydrolysis process is the Greenwoolf project 'Recycling wool waste into protein hydrolysates for organic farming'. The fertilizer obtained can be liquid or solid, in pellet form, and is currently being tested in the field on vineyards and small fruits. It would therefore be capable of nourishing extensive crops such as vines in a completely natural and cost-effective way. This is not a small-scale "niche" recycling project, but a method capable of relieving sheep farmers of the cost of wool that cannot be used for textiles, reviving industrial production of machinery for the Italian and foreign markets, and spreading good organic farming practices.

Wool, like hair and nails, is mostly composed of keratin, a protein [1, 2]. Breaking it down to make its substances available is common practice. The dirty wool is placed in a reactor with water at around 170 °C for one hour. The reactor rotates around an axis that allows the water to penetrate the entire surface and inside the wool using saturated steam produced by a boiler. Controlled hydrolysis with superheated water breaks down keratin into simpler compounds. Due to its characteristics, wool, when treated, is an exceptional soil conditioner because it provides carbon, nitrogen, and sulfur, the main nutrients for plants. However, its use in its raw state is not recommended because infections can occur due to the very slow biodegradation process. In fact, wool is classified as a category 3 by-product, the disposal of which is regulated by EU Regulation 142 of 2011. The novelty of the district's project lies in the fact that, after the process, the wool returns to the animal through grazing, thanks to agricultural practices. This disposal system offers several advantages: - environmental: the sulfide bonds in wool, which make it dangerous when burned, are useful in this case because the sulfur added to the fields acts as a fertilizer and fungicide 40 - agronomic: soil structure is improved through the absorption of excess water (water retention). Economically, the costs of synthetic fertilizers are reduced. The profits of sheep farms are increased [3].

3 Wool Products

The other strand concerns the use of wool in traditional crafts which, thanks to the rediscovery of ancient manual skills, can produce true works of art. In central Sicily, unused wool can be put to further use that should not be overlooked [1, 2]. Felt is a "non-woven fabric" obtained through a process called felting. In this process, the wool fibers are intertwined, arranged in a single direction, and pressed manually with the aid of hot water and soap. Clearly, this is a process that does not require any special tools, is completely natural, and does not require the addition of chemicals. The result is an elastic fabric that is perfect for creating clothing, furnishing fabrics, and much more.

It also has remarkable thermal insulation properties against both heat and cold, due to the air trapped inside the wool during processing. Another strength of this product is its hygroscopicity. Felt is capable of storing 20–25% water when wet and 50% when dripping. The production of felt in Sicily offers opportunities not only to make use of a resource that would otherwise be wasted, but also to revive small historic production businesses whose ancient art deserves further exploration.

4 Current Practices

Some local communities have developed the "Tramando s'innova" project in collaboration with other specialized entities such as the Agenzia Lane d'Italia, which, with "Woolscape" is promoting a virtuous relationship between textile production and cultural and landscape heritage, while also mapping the wool industry region by region, reconstructing the identity of Italian wool, which can provide ideas for potential applications.

One need only observe nature to grasp its suggestions. Sheep's wool, for example, can be used to insulate our homes. The panels that make up the insulation have characteristics that allow them to compete very well with traditional building materials. Among the successful experiences in relation to its use in the construction sector, Edilana is worth mentioning. The Edilana company was founded in Sardinia with the aim of creating wool products using wool from Sardinian farms as its raw material. This company manufactures innovative products for use not only in agriculture but also in construction and furniture. The company immediately committed itself to promoting not only raw material but also respect for environmental issues. In the construction sector, the company decided to invest in the creation of a panel made from wool from native Sardinian sheep. The panel exploits the extraordinary properties of wool fibers, which, thanks to their high keratin content, are able to bind and eliminate many toxic substances. This interesting depolluting capacity allows it to absorb and neutralize smog, fine dust, heavy metals, and many substances harmful to health used in the construction industry. It can be used not only to create healthy living spaces but also to renovate and remediate buildings constructed in the past with materials that release harmful gases. Edilana panels, in combination with fir strips and sheep's wool, are used in PRONTOMAT for their acoustic and thermal insulation properties.

Edilana Design, on the other hand, manufactures padded garments: pillows for neck and back pain, postpartum pillows, therapeutic duvets and jackets, and garments that limit excessive sweating. In addition to saving over 60% of water, they strengthen, nourish, and protect the soil. The products do not need to be disposed of, they degrade slowly into the soil, increasing their fertility, and they reduce CO2, making them particularly environmentally friendly. In Friuli-Venezia Giulia, the start-up Agrivello, in collaboration with the University of Udine, the Friuli Centrale University Health Authority, and the Friuli Foundation, has led to the creation of the experimental project "Agrilana in pellet."

Among the companies operating in the field of wool application in the environmental and naturalistic sectors are the Pro Patrimonio Montano PatriMont network, Brebey, a Sardinian cooperative founded in 2012 that produces sheep wool-based panels, the

Sicilian Wool Production District based in Cammarata (AG) in the heart of the Sicani Mountains, as well as Mariantonia Urru Tessuti e Tappeti Sardi and the Valcamonica Wool Tail Association. With specific reference to the use of wool in naturalistic engineering projects, we can look to Turkey, where sheep's wool is used to combat erosion of agricultural land. In Turkey's hilly landscapes, farmers have long faced a crucial challenge: soil erosion and rapid rainwater runoff. These phenomena, exacerbated by climate change and intensive land use, reduce soil fertility and jeopardize agricultural productivity.

In Italy, according to Istat data from 2017, 8,200 tons of raw wool are produced each year from the shearing of six million sheep [2, 3]. As mentioned, wool can be used as it is, mixed with soil to retain moisture and slowly nourish plants, or transformed into pellets that release nutrients (nitrogen) and are ideal for vegetable gardens, orchards, and pots. It is an ecological alternative to chemical fertilizers, improves soil structure, and reduces environmental impact.

5 Methods: Nature-Based Engineering and Potential Applications of Wool

Nature-based engineering, as is well known, studies how living plant components (plants or parts thereof) can be used as building materials in combination with non-cementitious aggregates such as stone, earth, wood, and steel, as well as in combination with mats made of plant or synthetic fibers, mainly for hydrogeological stabilization projects related to soil consolidation in areas subject to erosion. The use of living materials for various purposes is a fairly ancient practice, but a strong impetus for the development of naturalistic engineering began in the 1990s in response to the need to simultaneously secure areas at risk of hydrogeological instability and protect the environment by minimizing the environmental impact of soil protection works. It is a cross-disciplinary science that, due to its many possible applications, requires technicians to have a basic knowledge of several scientific disciplines, which are integrated depending on the complexity of the context of intervention. Naturalistic engineering techniques [2–4] perform multiple functions and involve the use of different natural materials. Processed wool-in the form of bricks, geomats, or biomats[2] can be combined with plants and wood material.

Plants play a fundamental role in preventing hydrogeological instability by stabilizing slopes and banks from both a hydrological and mechanical point of view. In the first case, by intercepting rain, they protect the soil from splash detachment and increase evapotranspiration; in the second case, through their roots, they perform a cohesive action on the soil, protecting it from erosion linked to the surface flow of runoff water. When natural engineering techniques are applied to riverbank protection in river environments, they offer additional benefits by reducing the lateral expansion of watercourses and promoting the re-naturalization and strengthening of the ecological role of the river corridor through the development of favorable conditions (shading, reduction of sediment input,

[2] They are generally classified according to whether they are natural, made from plant fibers such as wood, coconut, and straw (e.g., bio-mats), or industrial, made from synthetic materials (e.g., geomats). They perform a variety of tasks, including erosion prevention, vegetation support, drainage, and soil waterproofing.

removal of pollutants, etc.) Finally, the vegetation component plays a role in mitigating environmental impact and has strong aesthetic and landscape value. For this reason, natural engineering works often fall into the broader category of nature-based solutions [5, 6].

Plant material includes seeds, cuttings, stakes, branches, and turf, which are used in different ways depending on site characteristics and the purpose of the intervention (erosion reduction, surface stabilization, etc.). There are precise rules governing their use and requirements necessary for the success of the interventions, including being native species and having a fast regenerative capacity, good technical characteristics, and a deep root system. Among the most suitable species are willows, poplars, alders, and tamarisks [5–7]. Wool bricks, geomats, or wool biomats can be associated with plants in naturalistic engineering works.

Wooden material essentially performs a supporting function, especially in the phase immediately following the completion of the intervention when the plant component is not yet sufficiently developed and able to perform all its functions. Mainly logs of various sizes belonging to tree species with good characteristics in terms of density, durability, and resistance (e.g., chestnut, fir, larch) are used. If large, it is used for support and consolidation purposes, otherwise as filling material, for example in gabions and pilings [6, 7].

In river environments, in particular, it provides suitable solutions for protecting the foot of the banks from erosion – thanks to its high resistance to the forces exerted by currents, as well as for the construction of structures directly in the riverbed with ecological functions, such as fish ladders. Wool bricks for filling gabions, geomats, or biomats can be combined with other wood materials in naturalistic engineering works.

6 Results: Characteristics and Applications of Wool

Sheep's wool is a renewable product because it grows back on animals every year. It has excellent thermal and sound insulation properties, is breathable, hygroscopic, and self-extinguishing because it does not burn or distribute heat. The natural function of wool is to protect animals from the elements and insulate them from heat and cold. Sheep's wool is often considered a waste product of farming and underutilized, but in reality, wool is a valuable material: it is breathable and retains water, is completely biodegradable, enriches the soil by decomposing slowly and releasing nitrogen and nutrients, and acts as a natural barrier against erosion. To address this problem, the idea was born to use bricks made from compressed sheep's wool to build sloping flower beds and agricultural terraces [8]. Wool is used as thermal and acoustic insulation in wall cavities, in internal and external cladding exposed to wind, in false ceilings, in partition walls, and as acoustic insulation panels. In addition to its various uses, it also offers a range of interesting application methods, as it can be used loose, in rolls, or in panels ranging from 20 to 80 mm for the following applications:

- Filling wool, which is used in cracks or frames as insulation.
- Insulating rolls that can be cut and worked with extreme ease. They offer uniform mechanical resistance and can be used in walls, counter walls, and roofs.

– Insulating panels, specifically for thermal and acoustic insulation of wooden and continuous floors.

Once sheared, the wool is washed, rinsed with sodium bicarbonate, and treated with boron salts, which not only make it more fire-resistant but also moth-proof. Carding is used to obtain the desired thicknesses, which can be reinforced with polypropylene fiber. To be used as a building material, the wool must be properly treated because, in the presence of moisture, the boron salts are washed away, making it susceptible to pests again. It can be seen that wool, considered a waste product, has all the right qualities to be valued and used in a myriad of different ways, each of which respects the environment. Given the abundance of the product and its easy availability, especially in western Sicily, we can conclude that not exploiting its potential is not only an economic waste but also a moral one. Its great abundance, the simplicity of the production processes it undergoes, and the wide range of uses can succeed in giving value and utility to this product from our sheep.

7 Proposal Model: Areas of Application and Sustainability

The project aims to develop a virtuous model for the recovery and application of wool in the form of a material that is useful for protecting the land and respecting the environment [9–11][3].

Wool Bricks
The blocks are densely packed and molded into interlocking structures. Placed on slopes, they create layered platforms that stabilize the soil, retain moisture, reduce surface runoff, and promote crop growth without chemical additives.

Biomatts and Geomatts
Biomatts can be used for surface erosion control and covering (grass planting, biomatts, and geomatts), surface stabilization (together with piling, wattle fencing, and fascines), support/consolidation (combined with gabions and breakwaters), and rockfall protection.

In addition to this, there are also indirect environmental functions (Fig. 2) that are useful for:

– river and ecological redevelopment,
– restoration and re-naturalization,
– mitigation of environmental impacts.

Thanks to their versatility, they can be used in various contexts: on the banks of rivers, streams, and canals or directly in their beds, on unstable slopes, on railway embankments or road embankments, in abandoned areas and quarries, and in coastal and lagoon areas.

Here are some examples of the most common types of natural engineering works and techniques used in Italy, according to the methods of implementation and construction:

[3] ISPRA, Tipologia di opere e tecniche di ingegneria naturalistica https://www.isprambiente.gov.it/contentfiles/00000400/431-tb-battistella3.pdf (Available in Febrary 2026).

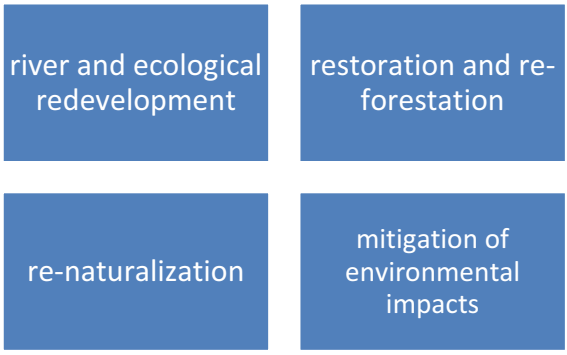

Fig. 2. Indirect environmental functions, credit: Celestina Fazia

stone gabions, box gabions, reinforced green terramesh, hydraulic riverbank stabilisation (riverbank gabions) and slope stabilisation (wickerwork, terraces and live cordonata, live grating, simple palisade, trellis, double-walled piling, reinforced and/or reinforced earth) [10, 11]. These techniques are used to secure slopes, restore riverbeds, stabilize coastal dunes, reinforce road embankments, and reclaim quarries. Compared to traditional techniques, they have a lower environmental impact and blend in better with the landscape.

7.1 Externalities of a Project for the Use of Wool in the Sicily Region

The innovation that a project for the reuse of wool in naturalistic engineering works aims to introduce concerns the transformation process: the production of bricks made from compressed sheep's wool to build sloping flower beds and agricultural terraces, but also the production of other materials, panels or geo-mats for naturalistic engineering, becomes an innovative process when wool is successfully transformed - from shearing to processing - into a low-impact green product. Sicily is the leading region in Italy in terms of UAA (Utilised Agricultural Area), with 1.342 million hectares, and ranks second in terms of the number of active farms, with 142,416. It is the Italian region with the largest area of organic farming (338,000 ha). In order to mitigate the socio-economic decline of inland areas, it is necessary to develop rural entrepreneurship. Section 2 of the CSR (Complemento di programmazione per lo Sviluppo Rurale, or Rural Development Programme Supplement) for Sicily refers to the need to promote transition, research and technological innovation [12]. The tourism objective is closely linked to the rural landscape of historical interest, agricultural practices and traditional knowledge [12, 13].

UNESCO recently recognised the dry stone walls found in Sicily. They play a fundamental role in the landscape, the environment and the defence of the territory, helping to prevent landslides and flooding. The presence of dry stone walls helps to combat erosion, desertification and soil salinisation. They are advantageous because the materials can be sourced locally, but they are not always suitable for containing clayey embankments, requiring commitment and skill to build.

The idea is consistent with the provisions of the EIP, European Innovation Partnership (Reg. (EU) 2021/2115), as the use of low-impact green materials places it in the virtuous

cycle of sustainable development, increasing the competitiveness of farms in both the short and long term, thanks to a gradual approach to research and technology transfer. Furthermore, through the use of circular economy materials, it will be easier and more effective to intervene to preserve the soil and habitats and improve the ecosystem services closely linked to sheep farming [3].

The Sicilian wool district is responsible for promoting wool. Wool is renewable, has thermal and sound insulation properties, is hygroscopic and self-extinguishing, retains water, is biodegradable, enriches the soil by decomposing slowly and releasing nitrogen and nutrients, and acts as a natural barrier against erosion. However, its use in its raw state is not recommended due to its very slow biodegradation process. In fact, wool is classified as a category 3 by-product, the disposal of which is regulated by EU Regulation 142/2011 [11–13].

The use of wool for different purposes, which allows it to be sanitised without costly and environmentally harmful processes, specifically for bricks or wool-based products used to contain embankments or slopes in natural engineering works and to delimit cultivated areas, is in line with CSR objectives [12, 13].

8 Conclusion: Agricultural and Environmental Benefits

Farmers can use beds made from wool bricks to plant vegetables, herbs, and even fruit bushes. Every drop of rain is absorbed and stored in the soil instead of running off [10]. The slow release of nutrients from the decomposition of wool supports healthy and vigorous plant growth, reducing the need for synthetic fertilizers. The effects on the environment are noteworthy. This practice not only transforms waste material into a resource, but is also a concrete example of regenerative agriculture:

- it reduces waste and costs,
- improves soil fertility,
- combats erosion and desertification,
- supports rural communities with low environmental impact solutions.

It is a demonstration of how innovation can arise from respect for nature and the intuition to make the most of existing resources [5]. The use of wool helps to halt and reverse the process of biodiversity loss, strengthen ecosystem services, and preserve habitats and landscapes. Wool is an economic resource, but it also carries values and culture. Reviving wool means supporting the territories and those who care for them, first and foremost the shepherds. But that's not all.

Many Italian landscapes have unique features that must be preserved even when it is necessary to intervene to protect embankments and slopes. The field of naturalistic engineering, created to introduce effective intervention methods with low environmental impact, is one of the possible contexts in which this material can be used. Through the use of wool bricks, for example, it will help to preserve the historical elements of the rural landscape while improving the integration of defensive structures into the landscape.

It is important to emphasize that the research findings are consistent with Specific Objective 5 of the PAC (Common Agricultural Policy of the European Union) "to promote sustainable development and the efficient management of natural resources such

as water, soil, and air, including by reducing reliance on chemicals," as it is based on the recovery of sheep's wool through a sustainable process that involves low use of energy, environmental resources, and chemicals. Furthermore, it contributes to halting and reversing the loss of biodiversity, strengthening ecosystem services, and preserving habitats and the landscape. Wool is an economic resource but also carries cultural and symbolic value. Revitalizing wool means supporting local communities and those who care for them, first and foremost the shepherds. But that's not all. Many Italian landscapes possess unique characteristics that must be preserved even when intervention is necessary to protect embankments and slopes. The field of naturalistic engineering, which emerged with the goal of introducing intervention methods that are effective and have minimal environmental impact, is one potential context for the material's use. It will help, through the use of materials such as wool bricks, to preserve the historical and cultural elements of the rural landscape while improving the integration of protective structures into the landscape.

It would be both possible and desirable to identify the network of businesses that use the new product—the result of circular economies arising from the transformation of a local product— since, through the use of low-impact green materials, the company that uses "processed" wool for eco-friendly materials positions itself within the virtuous cycle of sustainable development, increasing the competitiveness of agricultural businesses—both in the short and long term—thanks to a gradual shift toward research and technology transfer.

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