

Rebuilding the Wool Value Chain

Barriers and Enablers to Sheep Wool Valorisation in Slovakia

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Abstract

Sheep wool is a renewable biological material with diverse potential applications. Despite its continuous availability and growing interest in circular bioeconomy approaches, it is increasingly regarded as a low-value by-product or waste in most European countries. This thesis aims to identify the systemic conditions that shape the valorisation of sheep wool in Slovakia and to assess how the current wool system could be strengthened to form a more functional value chain. To achieve this, the Slovak wool sector is analysed through the combined lenses of the Technological Innovation Systems framework and a value chain perspective.

The Slovak wool value chain is structurally incomplete. Although relevant actors are present, they remain weakly connected, limiting coordination across the system. The greatest value loss occurs in the “missing middle” between farms and processors, where the absence of an organised collection system results in most wool being either exported as a low-value raw material or discarded as waste. In addition, the system's overall performance is weak. Entrepreneurial activity emerges as the strongest and most promising system function, driven by motivated actors experimenting with new wool applications. In contrast, the weakest function is the guidance of search, reflecting the absence of a clear strategic direction and institutional support. The Slovak wool valorisation therefore requires a simple but sufficient system to enable transactions. A nationally recognised coordinating body is proposed to connect actors, aggregate supply, introduce wool classification, create fair price signals, thereby building a system capable of turning wool's potential into organised value.

Keywords: sheep wool; wool valorisation; Slovakia; bioeconomy; value chain; Technological Innovation Systems.

Executive Summary

Problem definition

Despite growing interest in circular bioeconomy systems, on average, 75% of European sheep wool continues to be discarded or treated as a low-value by-product (Iofrida et al., 2025). From a bioeconomy perspective, improved utilisation of domestically produced wool would not only reduce the disposal of a renewable biological resource but also create additional value within rural economies and support the substitution of fossil-based materials throughout sectors (European Commission, 2025). However, the extent of wool underutilisation varies considerably across countries, suggesting that the problem cannot be explained by wool's material properties alone. Instead, wool becomes valuable only when system-wide conditions are in place.

A substantial body of literature examines wool's material properties and possible applications (Allafi et al., 2020; Rajabinejad et al., 2019), yet the evidence base on barriers is dominated by technical and policy reports rather than academic research. Existing studies also focus mainly on countries with relatively developed wool systems or on specific product innovations. Far fewer studies investigate why raw wool is still treated as waste in practice, and almost no literature has been identified on Slovakia. European policy discussions likewise recognise the need for national, context-specific analysis (EU CAP Network, 2025), because knowing these conditions is important not only for decision-making inside the national wool sector but also for wider efforts to strengthen a European system within bioeconomy frameworks that benefit all member states.

Aim and RQs

This thesis aims to identify the system-wide conditions shaping the valorisation of sheep wool in Slovakia and to assess how the current wool system could be strengthened to form a more functional value chain. Grounded in this aim, the research questions for this study are:

- RQ1** How is the Slovak sheep wool value chain currently structured and organised?
- RQ2** How do key system functions of the Slovak wool sector perform in enabling value chain development?
- RQ3** Which barriers and enablers explain the current performance of system functions in the Slovak wool sector?

Research design and methods

To achieve the aim of the study, this thesis adopts a qualitative single-case study design, focusing on Slovakia as the empirical case. The research is based on 12 semi-structured interviews with actors across the Slovak wool value chain, including farmers, market actors, and intermediary organisations.

The analysis combines a value chain perspective with the Technological Innovation Systems (TIS) framework. In the first path, the value chain perspective is used to examine how the Slovak wool sector is currently organised, addressing RQ1. The purpose is to identify key actors, activities, material flows, bottlenecks, and areas of value creation and loss. An initial value chain map is developed through desk research and then refined using interview data. In the second path, the analysis applies the TIS framework to assess the performance of the seven system functions, measuring it against the guiding questions and using a four-level scale: very

weak, weak, moderate, and strong. In parallel, the analysis pinpoints barriers and enablers affecting each function and the system as a whole. This path addresses RQ2 and RQ3. Finally, the findings from both analytical paths are synthesised to identify leverage points for stronger wool valorisation.

Main findings

The study determines that the Slovak wool value chain is structurally incomplete. Slovakia has farmers, shearers, traders, textile actors, emerging construction and agricultural applications, sectoral organisations, knowledge support actors, and civic initiatives, who all contribute to value creation. However, these actors are connected only weakly and therefore unable to transform the system when working in isolation. The main bottleneck occurs in the “missing middle”, between farms and processors, where wool is not systematically collected. Wool is then often treated as waste or exported in low-value form, resulting in value loss for Slovakia in both cases. At the same time, domestic wool-based businesses opt for imported, already-scoured wool because consistent Slovak wool of suitable quality and volume is difficult to access.

The TIS analysis shows that none of the seven system functions (F1-F7) performs strongly. Entrepreneurial activity (F1) is the strongest function, driven by motivated actors experimenting with wool-based products throughout various applications. Market formation (F5) and legitimisation (F7) are also emerging, supported by growing customer demand for natural and local materials. However, these developments remain concentrated in niche markets and, therefore, are too slow to trigger wider change. The weakest function is guidance of search (F4), reflecting the absence of a clear strategic direction and institutional support. Knowledge development (F2) and diffusion (F3) are also weak, as communication channels remain limited; a shortcoming that stems directly from the lack of a responsible coordinating body to oversee them. Lastly, resource mobilisation (F6) varies across sectors. It appears stronger in construction and agricultural applications where actors are frequently better positioned to handle larger and lower-grade wool volumes. In contrast, it remains weaker in the textile sector, where actors face stronger constraints because they depend on several missing or inaccessible processing stages, particularly scouring capacity.

The study detects three main systemic barriers explaining the overall weak functional performance. First, fragmentation across the value chain prevents aggregation of wool and mutual learning. Second, the sector is trapped in a self-reinforcing vicious cycle of low demand, low prices, and therefore low incentives for quality improvement or investment. Third, the absence of a coordinating body or institutional framework means that no actor currently takes responsibility for organising the system as a whole.

On the other hand, the main enablers in the system are highly driven and active actors committed to building the system bottom up, a strong cultural heritage of sheep farming, emerging applications with potential to process high volumes of wool, growing demand in natural materials, and Slovakia’s relatively small scale, which could make coordination feasible with a less complex system sufficient to organise the wool value chain.

Practical implications

Based on the evidence, Slovak wool valorisation should not be built around one dominant end-use. Different actors need different wool qualities and are therefore not necessarily competing for the same material. Textile actors need smaller volumes of cleaner, better-prepared wool; actors in the construction sector can absorb larger volumes of coarser wool; and agricultural uses can provide an outlet for low-quality “waste” fibres. The priority is therefore to create a system that distributes resources to their highest and most suitable use to increase the total value.

To enable this allocation, Slovakia needs a recognised coordinating body with a clear operational mandate, because the system is unlikely to self-organise. This body should coordinate the actors to build a wool collection system. Public support should focus on the missing middle of the value chain: a collection hub with sorting capacity, as this infrastructure serves broader sectoral needs. Within this hub, wool should be sorted using a simple use-based classification system sufficient to enable transactions through negotiations with buyers and farmers. This classification should be determined by actual buyer requirements and linked to differentiated prices, so that farmers are fairly compensated for the wool they deliver.

In the short to medium term, Slovakia should not rush into building a domestic scouring capacity. Aggregated wool volumes can be scoured and processed in the available facilities in neighbouring countries until the system stabilises. A domestic scouring line should only be considered once its financial viability is clearer.

Finally, future research should directly support implementation by generating data on precise wool volumes and quality, buyer requirements, logistics costs, and the coordinating body's financial model, because Slovak wool does not need more proof of its potential. It needs a system capable of turning that potential into organised value.

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1 Introduction

Global resource consumption is increasing rapidly. According to the United Nations Environment Programme (2024), it is projected to rise by around 60% by 2060 compared with 2020 levels, which is largely caused by continuing population growth and industrial production. As demand for materials and energy keeps rising, pressure on ecosystems is intensifying. Consequently, humanity is now consuming natural resources much faster than the Earth can renew them, and current levels of resource use already correspond to approximately 1.7 Earths (Global Footprint Network, 2025). This becomes particularly evident through Earth Overshoot Day, the date when humanity's demand for ecological resources exceeds what the Earth can regenerate in a single year. In 2025, this day was reached already on the 24th of July (Geneva Environment Network, 2025).

This pressure is not only a question of finding new resources, but also of making better use of renewable materials already produced within existing systems. Substantial volumes of biological materials generated within agriculture remain overlooked, despite their environmental benefits and unrealised practical and economic potential.

Sheep wool illustrates this situation well. Wool is a renewable fibre that is continuously produced as part of normal animal growth and must be removed once or twice a year for animal welfare reasons (Rajabinejad et al., 2019). Sheep are among the oldest domesticated livestock species, appreciated for their adaptability and flexibility to different environments, which makes them the most widely kept farm animals worldwide (Makovický et al., 2016). Despite that, wool has lost much of its former economic significance within global textile markets. Among other natural textiles, it has slowly been replaced by plastics and synthetic fibres, which have become prevalent since the mid-20th century. Synthetic fibres now account for approximately 61.4% of global fibre production (Rajabinejad et al., 2019). Over the same period, wool's share of total world fibre supply declined from 9.9% in 1960 to 3.2% in 2000 (Kilduff, 2002; Rajabinejad et al., 2019), before stabilising at around 3% since 2013. With respect to these figures, wool has increasingly come to be perceived as a marginal fibre, reserved primarily for luxury and high-end textile products (Rajabinejad et al., 2019).

This decline in economic significance is also reflected in the situation of European wool production, which continues regardless of market demand, generating more than 200,000 tonnes annually (Szczecina et al., 2026). Among the largest producers in Europe are Turkey and the United Kingdom (UK) (Farrell, 2020; IWTO, 2022; Rossi, 2017). Within the European Union (EU), the leading producers are Spain (25%), followed by Romania (17%), Greece (13%), France (12%), and Italy (11%) (F. Camilli et al., 2025; European Commission, 2022, 2025). Despite this domestic production base, European textile industries keep importing fine wool from major world producers such as Australia, New Zealand, and China (Eurogroup for Animals, 2020; Giannetti & Manfra, 2025; IWTO, 2022). These imports further weakened many domestic wool sectors, particularly since the liberalisation of global textile trade in the 1990s (Axfoundation & Norion Consult, 2025).

The consequences of this declining market relevance extend beyond wool's reduced share of global fibre markets. A growing proportion of European wool never enters formal markets at all. Rajabinejad et al. (2019) note that available statistics largely capture only traded wool processed into manufactured products, while excluding raw wool that remains on farms due to low quality, lack of buyers, or insufficient collection and processing infrastructure. The scale of this gap is considerable. Estimates suggest that only approximately 25% of European wool enters the market, while the remaining 75% is treated as waste or a low-value by-product (Iofrida et al., 2025). In many regions, farmers receive little or no compensation for wool, and disposal and shearing costs often exceed its market value (Rajabinejad et al., 2019). Consequently, practices such as burning or burying wool are not uncommon, making it difficult to estimate the true volume of wool lost as a resource across Europe (Rajabinejad

et al., 2019; Zoccola et al., 2015). Based on current estimates, approximately 150,000 tonnes of European wool may therefore fail to enter productive value chains annually.

The situation differs considerably in major wool-producing countries such as Australia and New Zealand. The difference is not simply that these countries produce larger volumes of wool, but that wool occupies a different position within their agricultural systems. Sheep farming is commonly structured around both meat and wool production, with wool treated as a co-product rather than a low-value by-product. In these contexts, wool remains integrated into established value chains and contributes directly to farm income. For example, wool contributes approximately 20–25% of typical farm-level revenue in New Zealand, whereas in the United Kingdom it rarely contributes more than 4% of farmers' income (Rajabinejad et al., 2019). This illustrates a wider paradox: a renewable material produced locally remains underutilised in many European regions, while imported fibres continue to dominate industrial supply chains.

The issue has increasingly attracted attention in European policy discussions. The European Commission (2025), in its *Communication A Strategic Framework for a Competitive and Sustainable EU Bioeconomy* (COM(2025) 960), outlines a framework to support the transition towards an economy that makes greater use of renewable biological resources across sectors such as food, materials, energy, and industry. By encouraging the use of biomass as an alternative to fossil-based inputs, the framework aims to reduce environmental impacts, strengthen European resource security, and create new economic opportunities for rural regions.

Within this framework, the EU Common Agricultural Policy (CAP) Network launched a focus group on wool. According to the group's *Starting Paper*, the initiative brings together experts from different disciplines and Member States to generate knowledge and develop recommendations for strengthening European wool value chains (EU CAP Network, 2025). Central to its work is the recognition that wool plays very different roles across Europe. In only a few countries, such as the UK, Norway, Iceland, and the Faroe Islands, wool remains integrated into functioning value chains and most of the national clip is utilised. Elsewhere, wool has largely lost its economic value. Reliable statistics remain scarce and difficult to compare across countries, but the available evidence shows substantial variation. The Nordic countries are among the best-documented cases, with recent estimates indicating that Denmark and Finland waste around 70–80% of annual wool output, while Sweden wastes around 50% (Axfoundation & Norion Consult, 2025). For comparison, in Italy, as little as 5% of the produced wool finds cost-effective applications (Vagnoni et al., 2016). Accordingly, the EU CAP group seeks to identify supply and demand challenges and opportunities specific to national contexts, recognising that a stronger European wool system that benefits all member states must be built from an understanding of these differences.

As the variation across Europe suggests, wool underutilisation cannot be explained solely by the fibre's physical properties or technical potential. Rather, existing research shows that the economic value of biological resources depends on wider systemic conditions, including infrastructure, actor coordination, institutional support, market demand, and governance arrangements (Hebrok et al., 2012; Van Acker et al., 2023). Where these conditions are weak, even technically suitable materials may remain underused.

1.1 Problem definition

Although interest in the topic is increasing, research on raw sheep wool remains uneven in its focus. A substantial body of literature examines wool's material properties and potential applications (e.g., Allafi et al., 2020; Rajabinejad et al., 2019), providing valuable insights into how wool can be transformed into higher-value products. However, these studies often consider the material after processing, rather than the conditions required for wool to enter functional value chains in the first

place. Broader discussions of barriers, coordination challenges, and sector-level constraints are more commonly found in policy or sectoral reports (e.g., Axfoundation & Norion Consult, 2025; Department for Environment, Food & Rural Affairs, 2023; EU CAP Network, 2025).

Existing studies and reports also tend to focus on countries with relatively well-developed wool systems, particularly Norway (Hebrok et al., 2012; Klepp & Tobiasson, 2019), or on specific innovations and niche applications. Consequently, less attention has been given to regions where raw wool has lost its market value and is treated primarily as a waste stream or low-value by-product. One such example is by Parlato et al. (2022), who examined the spatial distribution of sheep farms in Sicily and identified suitable locations for wool collection centres demonstrating the importance of organising supply as a first step towards valorisation. However, comparable studies examining underdeveloped wool systems and the factors shaping their current functioning remain scarce.

Within this context, Slovakia therefore represents a relevant case for this analysis. Although sheep farming has long-standing cultural significance in the country, raw wool remains only weakly integrated into economic value chains. Špinková's (2025) study provides important background by showing how local wool in the Czech and Slovak context has been devalued following economic and structural changes in the agricultural and textile sectors, while also highlighting emerging initiatives that seek to revalue wool through community-based practices. However, her study does not systematically analyse the Slovak wool sector as a value chain or innovation system. Therefore, there is limited systematic knowledge on how the Slovak wool sector is currently organised, what and how the barriers constrain valorisation, and what conditions may enable stronger utilisation. By filling this gap, this thesis can support national policy and market decisions intended at strengthen the Slovak wool sector and contribute to broader bioeconomy efforts to build circular bio-based value chains.

1.2 Background: The Slovak wool system

Sheep pastoralism, known in Slovakia as *salašnictvo*, has long been part of rural livelihoods in the country's mountainous regions. Since the late medieval period, sheep farming has been established, and wool has formed an important resource for local communities. By the eighteenth century, wool supported a range of local crafts and early manufacturing activities. It was traditionally processed within households and small workshops through carding, spinning, weaving, knitting, and felting to produce textiles and clothing for everyday use (Zajonc, n.d.-b). One of the important materials was *súkeno*, a dense, fulled woollen cloth made by weaving wool and then beating and shrinking it until it becomes felt-like. Coarser types of this textile were used for items such as *kapce* (footwear), *zápästníky* (wrist warmers), and *pokrovce* (small rugs) (Zajonc, n.d.-a). However, one of the most distinctive traditional woollen garments is *guba*, a long-haired, woven woollen coat which provided shepherds with warmth and rainproofing. Its hairy surface is created by inserting long, unspun wool fibres under the upper warp threads during weaving (Benža, n.d.). These woollen products still remain part of Slovak traditional clothing and material culture today.

During the socialist period (1948–1989), wool was the main commodity produced from sheep (NCC, 2003). At that time, the sector operated within a centrally coordinated industrial system. Raw wool was collected through state procurement schemes and transported to processing facilities across Czechoslovakia, mainly to large Czech woollen mills such as Karnola in Krnov and textile centres in Brno (Horák et al., 2011; Špinková, 2025). Later stages of textile and garment production were carried out in Slovak enterprises, including Slovena in Žilina and Tatrašvit in Svit, as well as many other smaller facilities in Skalica, Pezinok, Modra, and more. This structure ensured stable wool demand and provided farmers with reliable market access through fixed purchase prices and organised logistics.

Following the political and economic transition after 1989, the centrally coordinated system gradually collapsed. State procurement mechanisms and subsidies were withdrawn in the early 1990s, while privatisation and industrial restructuring disrupted previously established supply chains (Ryšková & Mertová, 2014; Špinková, 2025; Tučková et al., 2014). Between 1990 and 1999, the number of sheep in Slovakia decreased from around 600,000 to 340,000 heads (NCC, 2003). In parallel, many textile enterprises either downsized, went bankrupt, or shifted into other business activities. As a result, farmers no longer had stable buyers for large quantities of raw wool.

Today, sheep farming remains concentrated in rural and mountainous regions and is primarily oriented toward meat and dairy production (Makovický et al., 2016). These products generally provide higher and more reliable economic returns for farmers. According to Eurostat (2026), Slovakia recorded approximately 301,130 sheep in 2022, distributed across approximately 9,000 sheep herd holders, with around 35% of the sheep population owned by small individual farmers (Ministry of Agriculture and Rural Development of the Slovak Republic, 2021; Plemenárske služby SR (PSSR), 2025)

The national flock is dominated by traditional breeds well adapted to mountain conditions, most notably the Improved Valachian and Tsigai breeds (Figure 1 below), which typically produce mixed, relatively coarse wool. Merino-type sheep that produce fine fibres represent only a small share of the total population (NCC, 2003).



Figure 1. Most widespread sheep breeds in Slovakia: Tsigai (left) and Improved Valachian (right). Reproduced with permission from the civic organisation *Chováme doma* (n.d.-a, n.d.-b). Photos by Vladimír Líptai; commissioned by OZ *Chováme doma* for the book *Slovenský statok*.

1.3 Aim and research questions

This thesis aims to identify the system-wide conditions shaping the valorisation of sheep wool in Slovakia and to assess how the current wool system could be strengthened to form a more functional value chain. In this way, the aim is also to generate knowledge that can support actors seeking to strengthen the utilisation of biological resources in situations where the availability of biological resources alone has not been sufficient to drive value chain formation.

To achieve this aim, the study applies a value chain perspective and analyses the Slovak wool sector as a Technological Innovation System within the framework of the bioeconomy. It studies how interactions among actors, institutions, networks, and physical infrastructure influence the performance of key system functions required for coordinated economic activity to emerge around a bio-based resource and identifies the main barriers and enablers shaping this performance. Grounded in this aim, the research questions for this study are:

RQ1 How is the Slovak sheep wool value chain currently structured and organised?

- RQ2** How do key system functions of the Slovak wool sector perform in enabling value chain development?
- RQ3** Which barriers and enablers explain the current performance of system functions in the Slovak wool sector?

1.4 Scope and delimitations

This study is geographically bounded to Slovakia and examines the Slovak sheep wool sector as a single national case. Although wool underutilisation is a challenge shared by many European countries, a single-case design was chosen because value chain formation is strongly determined by national institutional arrangements, actor configurations, and infrastructural conditions (Kaplinsky & Morris, 2001). Studying the phenomenon across multiple countries simultaneously could therefore risk obscuring the mechanisms operating within a specific context. Against this background, Slovakia represents a relevant case. Wool continues to be produced annually and historically formed one of the main products of sheep farming, yet today it remains only weakly integrated into the economy. This makes Slovakia a meaningful site for examining why a coordinated value chain has not re-emerged. The scope goes beyond Slovakia in two cases. First, examples from other countries are explained in the literature review section. They serve a reference purpose in the discussion, as an indication of possible models and best practices in Europe, rather than as part of the empirical investigation. Second, in cases where Slovak wool crosses national borders for processing. This is noted and acknowledged to a certain point, where relevant, but not further investigated through primary data collection.

Thematically, the study centres specifically on sheep wool and does not extend to other natural fibres, animal by-products, or livestock sectors. This delimitation was necessary because sheep wool is highly diverse, with more than 1,000 sheep breeds producing different wool types with varying characteristics. Including additional animal fibres or livestock sectors would have considerably expanded the scope and reduced the rigour of analysis.

The analysis also concentrates on the upstream stages of the value chain, covering wool production, initial processing, and early-stage utilisation by market actors working with Slovak wool. Downstream consumers are not included in the primary data collection. However, they are recognised in the analysis as important actors shaping demand and influencing the performance of system functions. Upstream actors and stages have been prioritised because they are closest to the point where wool either enters the value chain or becomes waste.

The temporal scope of the study is limited to the current Slovak wool system. The analysis assesses how the system functions in 2026 and identifies the barriers and enablers shaping wool valorisation today. Historical background is included to contextualise the current situation, particularly by showing how the sector functioned before political and economic restructuring and by highlighting the cultural meaning of sheep farming and wool production in Slovakia.

1.5 Ethical considerations

This research adheres to ethical principles for social science research involving human participants. The study was reviewed against the criteria for research requiring ethics board approval. It was found not to require a formal ethics committee statement because it does not involve sensitive personal data or vulnerable participants. All interview participants received a consent form for participation in the research. This is provided in Appendix A. Participants were also informed in advance of the research's purpose, the topics to be discussed, and the expected duration of the interviews. Participation in the study was voluntary, and all participants were allowed to decline or withdraw at any moment without consequences.

To protect participants' privacy, all interviewees are anonymised in this thesis. Given the relatively small size of the Slovak wool sector, particular care was taken to avoid including information that could indirectly reveal identities. Interview recordings and transcripts were treated confidentially and stored securely on the author's password-protected personal computer. The recordings are used solely for this research and are deleted after the thesis defence.

This research was conducted independently and was not funded or supported by any external organisation. In addition, the author has no personal or professional connections in the Slovak wool sector. There is therefore no external influence over the analysis or interpretation of the results.

1.6 Audience

The audience for this thesis comprises policymakers and public authorities engaged in rural development, the bioeconomy, and agricultural policy at both the national and EU levels. This audience includes institutions involved in implementing bioeconomy frameworks, agricultural policies, and Slovak or other national strategies, particularly those desiring country-specific knowledge to inform targeted interventions in underperforming wool sectors.

Additionally, the audience consists of market actors and intermediary organisations operating within or adjacent to the Slovak wool system. This audience includes farmers, processors and other businesses working with wool-based products, sector associations, and civic initiatives. For these actors, the findings deliver a practical value chain map of the Slovak wool system and an overview of the conditions that limit or enable wool valorisation. This can support decision-making on resource allocation and targeted interventions.

The thesis also speaks to researchers in sustainability transitions and innovation systems studies, contributing to the growing body of work applying the TIS framework beyond a specific technology to situations where coordinated economic activity around a biological resource has yet to emerge.

1.7 Disposition

This thesis is structured as follows:

- **Section 1** defines the research problem, introduces the study's background, and presents the aim and research questions. It also outlines the scope, ethical considerations, and intended audience of the thesis.
- **Section 2** reviews the literature on wool as a biological material, including its main properties and value-determining characteristics, introduces wool valorisation within the bioeconomy, identifies barriers and enablers from the existing literature, and presents examples of more integrated wool systems in Europe.
- **Section 3** presents the Technological Innovation Systems framework and explains how its components are used to analyse the Slovak wool sector.
- **Section 4** describes the research design and methods, including data collection and the analysis of the empirical material.
- **Section 5** presents the findings and analysis. It first maps the current structure of the Slovak wool value chain. It then assesses the performance of the seven system functions and identifies the main barriers and enablers shaping wool valorisation.
- **Section 6** discusses the findings in relation to the overall research aim and identifies possible leverage points for stronger system development.
- Finally, **Section 7** concludes the thesis by summarising the main findings and recommending further steps.

2 Literature review

This literature review first introduces wool as a material by explaining its fibre structure and properties. It then outlines the characteristics that determine wool's value and fitness for diverse uses, followed by an explanation of classification systems used to sort and grade wool before processing and trade. The literature review then situates wool within the bioeconomy and outlines its possible applications across a range of sectors to preserve the highest value. It further reviews the main barriers and enablers shaping wool valorisation in Europe. Finally, it introduces the value chain perspective and presents examples of more integrated wool systems from Norway, the UK, and Iceland. Overall, this review provides the basis for analysing the Slovak wool sector.

2.1 Wool fibre structure and properties

Wool is a natural protein fibre continuously produced by sheep as part of their biological cycle and must be shorn annually or twice a year for animal welfare reasons, with each sheep yielding approximately 1.5–3 kg of fleece per year. The coat of wool removed from a sheep during shearing is called a fleece. Datta et al. (2023) report that raw fleece contains a significant proportion of impurities, typically ranging from 25% to 70% of fleece weight. Botha & Hunter (2010) estimated this number between 30 and 50%. The wool at this stage is also called greasy wool because it contains impurities such as grease (lanolin), moisture, dirt, and/or vegetable matter. The impurities are removed through a scouring process, washing wool using hot aqueous solutions with detergents. After scouring, wool contains 97% of proteins, along with small amounts of lipids and minerals (Giteru et al., 2022). Chemically, wool consists of carbon, hydrogen, oxygen, nitrogen, and sulphur, and is rich in sulphur-containing amino acids such as cystine, which form disulfide bonds that contribute to fibre strength and resilience.

Figure 2 illustrates the structural composition of the wool fibre, which includes three main components: the cuticle, the cortex, and, in some fibres, a central medulla (Braaten, 2005; Grishanov, 2011). The cuticle forms the outermost layer, consisting of thin overlapping cells that constitute approximately 10% of the total fibre weight. Its lipid content gives the surface hydrophobic properties that repel liquid water and dirt. At the same time, the structure of the cuticle allows water vapour to diffuse into the hydrophilic core, so that wool can absorb significant amounts of moisture vapour without feeling wet (Braaten, 2005). This moisture-regulating capacity also means that wool does not attract mould and bacteria.

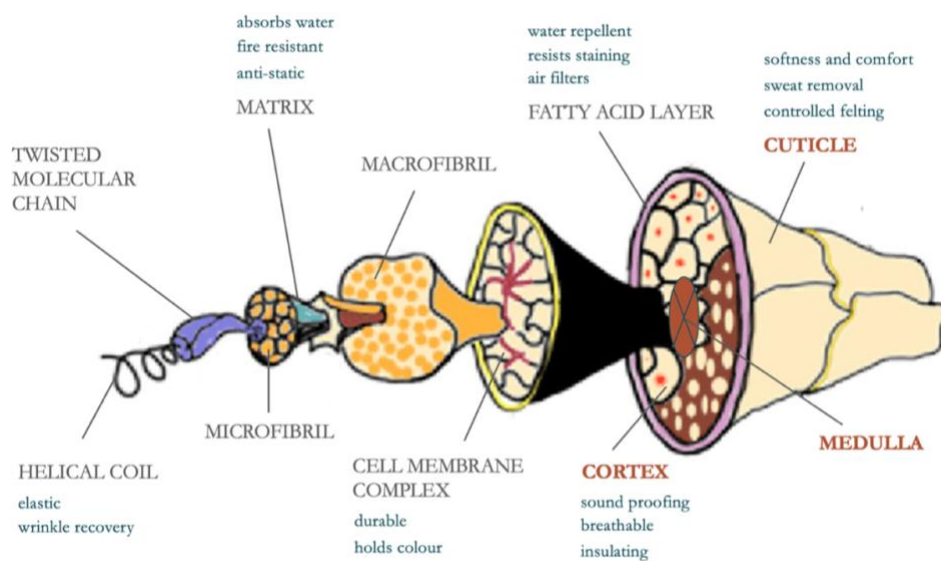


Figure 2. Wool fibre structure. Derivative figure based on Lancashire (2016), with author modifications informed by International Wool Textile Organisation (IWTO) (2024).

Beneath the cuticle lies the cortex, which makes up around 90% of the fibre and consists primarily of keratin protein (Braaten, 2005; Grishanov, 2011). Cortex is formed by elongated, spindle-shaped cells aligned along the fibre axis and is responsible for most of wool's mechanical and physical properties (Cardamone, 2010; Rajabinejad et al., 2019). This cell arrangement gives wool its natural elasticity, enabling it to return to its original shape after being stretched (IWTO, 2024). In general, wool fibres are highly flexible and can bend around 30,000 times without breaking (Braaten, 2005).

The medulla is the third main structural component of wool fibre. It is an air-filled cavity situated in the centre of the cortex. However, as the medulla is not present in all wool fibres, it was not visible in the original image from Lancashire (2016) used for Figure 2. Therefore, its expected location has been indicated schematically to illustrate where it would occur if present. Medullation tends to become more frequent and more pronounced as fibre diameter increases, and is therefore more typical of coarser fibres, which are generally associated with lower quality. Because trapped air within the cavity reduces heat transfer, medullated fibres enhance insulation properties and are therefore especially suitable for products such as insulation panels, carpets, and floor coverings (Braaten, 2005; Lakshmanan, 2022).

As explained, structural properties provide wool a distinctive combination of characteristics, including thermal and moisture regulation, sound insulation, absorbency, hypoallergenic properties, wrinkle resistance, strength, dirt repellence, biodegradability, and durability (Ngo, 2022; Rajabinejad et al., 2019). Wool is also naturally flame-resistant and difficult to ignite. Rather than burning, it tends to smoulder and can self-extinguish when the heat source is removed, making it safer than many synthetic fibres (Ngo, 2022). However, to preserve these characteristics, wool needs careful handling. If not properly maintained, it can be affected by insects such as moths, may discolour over time, especially after prolonged exposure to sunlight, can shrink when exposed to heat and lose strength when wet (Ngo, 2022). Both advantages and disadvantages are summarised in Table 1.

ADVANTAGES	DISADVANTAGES
Highly absorbent of pollutants and odours; breathable; comfortable; warm; lightweight; elastic; durable; easy to tailor; dyes well; wrinkle-resistant; naturally flame-resistant; recyclable; biodegradable; resistant to static electricity; hypoallergenic, resistant to bacteria and mould; and repels dust mites.	Susceptible to moth damage; may feel scratchy on skin; can shrink with heat and moisture; weakens when wet; may yellow with sunlight exposure; susceptible to damage by bleach and perspiration; and requires careful maintenance.

Table 1. Summary of the advantages and disadvantages of wool as a material. Derived from Braaten (2005); Ngo (2022)

2.2 Value-determining characteristics and classification systems

The practical and commercial value of wool, however, is not uniform across all fleeces, not even from the same breed. Factors such as breeding conditions, nutrition, general care, shearing technique, and weather, among others, further influence the quality of wool fibres (Botha & Hunter, 2010; Ngo, 2022). For example, prolonged wet conditions can reduce the amount of natural grease on the fibres, while cold weather can make them harder and heavier (Ngo, 2022). Nutritional stress or disease can reduce fibre growth and diameter, and poor shearing or handling may lower fleece quality through contamination or damage. Because of this variation, Botha & Hunter (2010) argue that making quality assessment is indispensable for efficient marketing and processing of wool.

Wool quality can be assessed through a set of measurable fibre properties that determine its appropriateness for various end uses. Among the most economically important are fibre diameter, yield and vegetable matter content, alongside staple length and strength, colour, crimp, and the degree of uniformity within the fleece (Botha & Hunter, 2010; Doyle et al., 2021). Fibre diameter, measured in microns (μm), is generally the most significant price determinant. The IWTO (2024) report presents a distribution of wool fibre diameters in relation to typical end uses. Finer fibres, approximately 14.5–20.5 μm , are used for soft next-to-skin apparel, with the finest grades suited to products such as underwear, babywear, scarves, and other high-quality garments. Medium wool, with a diameter of around 20.6–25 μm , is used for woven apparel, knitting yarns, and furnishings, such as thicker sweaters, socks, and blankets. Coarser fibres, above approximately 26–48 μm , are more commonly used for durable or technical applications such as rugs, upholstery, bedding, horticultural applications (such as fertiliser pellets, mulch mats, and soil conditioners), insulation, and carpets (Ngo, 2022). For context, Australia produces 95% of the world's wool finer than 19.6 μm (Doyle et al., 2021).

Another important property is yield: the proportion of clean, usable fibre remaining after scouring (Botha & Hunter, 2010). Impurities in the fleece make yield a critical commercial consideration for processors and buyers because wool with higher levels of vegetable matter can incur additional processing costs and fibre loss during cleaning (Botha & Hunter, 2010). Furthermore, staple length and strength are crucial for spinning efficiency, as weak or tender fibres are more likely to break during processing. Colour influences dyeability and market preference, while crimp contributes to elasticity, handle, and insulation performance. Uniformity of fibre diameter and length within a fleece is also valued because more consistent wool performs better during manufacturing and produces higher-quality finished products (Botha & Hunter, 2010). Notably, these characteristics should not be understood as dividing wool into usable and unusable categories. Rather, different wool grades suit different applications. Thus, wool quality is best understood as fitness for purpose.

To organise wool according to these characteristics, official classification systems are used to sort and grade raw fleece before trading and processing. Although the same core measurable characteristics are generally applied, classification systems vary across countries, having evolved in response to dominant local breeds and specific market organisation. According to Axfoundation (2025), formal national systems exist in only a limited number of European countries, including Norway (Norwegian Wool Standard, using 16 classes), Sweden (Swedish Wool Standard, using 6 quality types with subclasses), and the UK (British Wool Grading, using over 100 categories). In countries where such systems are in place, wool can be sorted into consistent categories and traded more efficiently at scale. However, establishing and operating such systems also becomes increasingly complex as the scale of the categories expands, requiring skilled human labour, administrative capacity, coordination, infrastructure, and sufficient throughput volumes to function efficiently. Nevertheless, the absence of a uniform European classification standard remains an open challenge, which the EU CAP Network focus group on wool has identified as a priority area for developing a more integrated European wool value chain (EU CAP Network, 2025).

2.3 Wool valorisation potential within bioeconomy

The concept of bioeconomy has developed considerably over time, yet a universally accepted definition remains elusive due to the diversity of sectors and resources it encompasses (Efken et al., 2016; Gottinger et al., 2025; Wydra, 2020). According to the World Economic Forum (2024), the bioeconomy refers to the production and utilisation of biological resources and biological processes to generate food, materials, and energy sustainably. The bioeconomy is widely framed as a key approach to addressing sustainability challenges related to resource efficiency and climate mitigation, while also cutting reliance on fossil-based systems. Closely related to the bioeconomy is the concept of the circular economy, which emphasises maintaining the value of materials and resources within economic systems for as long as possible (World Economic Forum, 2024). In this thesis, the

bioeconomy concept is used mainly to situate wool as an underutilised biological resource with potential to enter higher-value material applications rather than remain a low-value by-product or waste.

Reflecting the growing policy interest in bio-based economic systems, the European Commission has developed a series of strategies to strengthen the European Union's bioeconomy. Building on the 2012 EU Bioeconomy Strategy and its subsequent updates in 2018 and 2022, the current policy framework from 2025, *A Strategic Framework for a Competitive and Sustainable EU Bioeconomy* (COM(2025) 960), places greater emphasis on industrial uptake, market growth, competitiveness, and long-term resilience of bio-based sectors (European Commission, 2025). Within the framework, biological resources are linked to several product markets, including bio-based plastics, textiles, packaging, construction materials, chemicals, and fertilisers. Depending on their specific characteristics and applications, different wool types can contribute to all of these sectors.

At the national level, many European countries have developed their own bioeconomy strategies to guide domestic implementation. In Slovakia, only one of the country's eight regions, the Nitra Region, has a strategy fully dedicated to the bioeconomy (Kirchmayr-Novak, 2022). A national bioeconomy strategy is still under development, while a bioeconomy roadmap has recently been prepared under the BIOEAST initiative to guide future action (CEE2ACT, 2025). Although the roadmap proposes broad measures for the period 2026–2035, it is not a binding national strategy and does not set out wool-specific steps. Its thematic focus is wider, covering areas such as biomass and biowaste, organic fertilisers, carbon farming, and sustainable construction and packaging.

2.3.1 The biomass cascade

Central to the bioeconomy framework is the principle of cascading biomass use, according to which biological resources should first be directed towards the highest-value and longest-lifetime applications before being used for lower-value purposes such as energy and heat recovery (Stegmann et al., 2020). The wool fibre characteristics discussed in Section 2.1 make wool appropriate for diverse applications within the biomass cascade illustrated in Figure 3.



Figure 3. The biomass cascade pyramid. Adapted from Nordic Council of Ministers (2017).

At the highest value level, wool is utilised in specialised applications where small volumes generate high economic returns. Components derived from wool, such as keratin, lanolin, ceramides, and peptides, are used in pharmaceutical, cosmetic, and fine-chemical products (Allafi et al., 2020; Petek

& Logar, 2020). Lanolin, a waxy substance recovered from wool grease during scouring, is particularly essential in cosmetics and skin-applied pharmaceutical formulations owing to its emollient and protective properties (Burnett, 2024). Keratin has also been increasingly explored for biomedical applications, such as wound dressings that support healing and systems that can gradually release medicine into the body, due to its biocompatibility and biodegradability (Allafi et al., 2020).

Wool can further indirectly contribute to food and feed systems through pest repellents and horticultural applications, such as mulch mats, slow-release fertilisers, soil amendments, and soil-conditioning products, where it improves water retention and gradually releases nitrogen (Komorowska et al., 2022; Petek & Logar, 2020; Rajabinejad et al., 2019). Similarly, wool is applied in geotextiles for erosion control and land restoration. In addition, wool fibres have been investigated for environmental remediation, including the adsorption of oils, dyes, heavy metals, and volatile organic compounds (VOCs), due to their porous structure and high adsorption capacity. However, despite their relevance, such applications are considered lower in the cascading hierarchy because the material decomposes during use and contributes only indirectly to food systems.

At the intermediate value levels of cascade, wool is applied across a range of industrial and material uses that require larger volumes while still retaining significant value. These include applications in textiles, bioplastics, packaging, and construction materials. Traditional uses include fabrics and upholstery products such as clothing, carpets, bedding, mattresses, and vehicle interiors (Allafi et al., 2020). Beyond these established applications, wool fibres are also incorporated into bio-based polymers and composite materials and used as reinforcement in bioplastics. Additional applications include packaging solutions in which wool fibres are compressed to create a protective layer, replacing plastic bubble wrap. Lastly, due to its thermal and acoustic performance, as well as its natural flame resistance, wool has attracted attention in the construction sector as a breathable insulation material and for noise control in heavy machinery (Corscadden et al., 2014; Faruk et al., 2012; Parlato et al., 2022; Rajabinejad et al., 2019).

Finally, at the lowest value level, wool residues and processing waste are directed towards energy recovery or biofuel production. While this still represents a viable end-of-life pathway, it is considered the least preferred option within the cascading framework because it captures minimal material value (Stegmann et al., 2020). All these different applications illustrate wool's versatile potential and its ability to participate in multiple bio-based value chains.

2.4 Barriers and enablers shaping wool valorisation in Europe

2.4.1 Barriers

A growing body of literature suggests that the persistent underutilisation of sheep wool in Europe is not due to a lack of technical applications, but rather to multiple, interrelated barriers that constrain its incorporation into the economy. These barriers can be broadly grouped into economic, structural, institutional, and regulatory. Importantly, their relative significance varies across national and regional contexts due to differences in production systems and market organisation.

Economic and market-related barriers are consistently identified as central. Low and volatile demand, combined with very low prices, often means wool does not even cover the cost of shearing. In the UK¹, farmers must pay on average £1.5–£2 per sheep for shearing (Brundle, 2025; Ulster Farmers' Union, 2023), while receiving around £0.27 per kilogram of wool, corresponding to approximately £0.52 per fleece of one sheep. As illustrated in Table 2, this results in the lowest, or

¹ The United Kingdom is used here as an illustrative case because comparable market data were readily available. Although exact figures vary by country, the examples in this section illustrate broader patterns also observed in other European contexts.

even negative, profitability compared to meat (£8 per kilogram) and dairy (£1 per litre of milk) production, as well as other sheep-derived by-products (Brundle, 2025; Smith, 2026). This economic imbalance reduces incentives for farmers to invest resources in wool quality or actively engage in its marketing (Hebrok et al., 2012; Van Acker et al., 2023).

PRODUCT	PRICE/UNIT
wool	£0.27/kg (~£0.52/animal)
meat (lamb)	~£8/kg
milk	~£1/litre
lanolin	~£89/kg
skin	~£65/m ²
fat	~£4/kg
bones	~£2/kg
intestines	~£0.85/m

Table 2. Price comparison of sheep-derived products in the UK. Derived from Brundle (2025) and Smith (2026).

Figure 4 also demonstrates that real UK raw fleece sale values have declined from over £14 per kilogram in the early post-war period to below £1 per kilogram in 2019, representing a fall of more than 93% (Department for Environment, Food & Rural Affairs, 2023). Despite periodic volatility, the overall trend is strongly downward, showing the long-term decline in wool's economic value in agricultural markets. The low economic value is reinforced by a mismatch between industrial demand and locally available wool types. Modern processing systems tend to favour fine, homogeneous, and predominantly white fibres, which are not typical of many indigenous and mountain breeds across European regions. This reduces the compatibility of local wool with standardised industrial processes (Klepp & Tobiasson, 2022; Špinková, 2025). At the same time, the global move towards fast fashion and cheaper synthetic materials has further weakened wool's competitiveness and displaced it from many textile markets (Klepp & Tobiasson, 2022; Špinková, 2025).



Figure 4. UK fleece sale values. Reproduced from Department for Environment, Food & Rural Affairs (2023). Licensed under the Open Government Licence v3.0.

A further market-related barrier is that wool's environmental image is not straightforward. Wool is commonly perceived as a fibre with a relatively high environmental footprint compared to other alternatives (Henry, 2012; Rajabinejad et al., 2019). Figure 5 shows that most of wool's carbon footprint occurs during the production stage, which is particularly due to sheep grazing and methane emissions from enteric fermentation. But Wiedemann et al. (2015) demonstrated that these results are highly sensitive to allocation methods because environmental burdens must be distributed among multiple co-products (meat, milk, and wool). The share attributed to wool may therefore vary substantially, from as low as 4% to as high as 50%. Nevertheless, wool still performs better than synthetic fibres and some plant-based fibres overall, while also offering many benefits coming from its physical and chemical properties (Rajabinejad et al., 2019; Sovbetov, 2025).

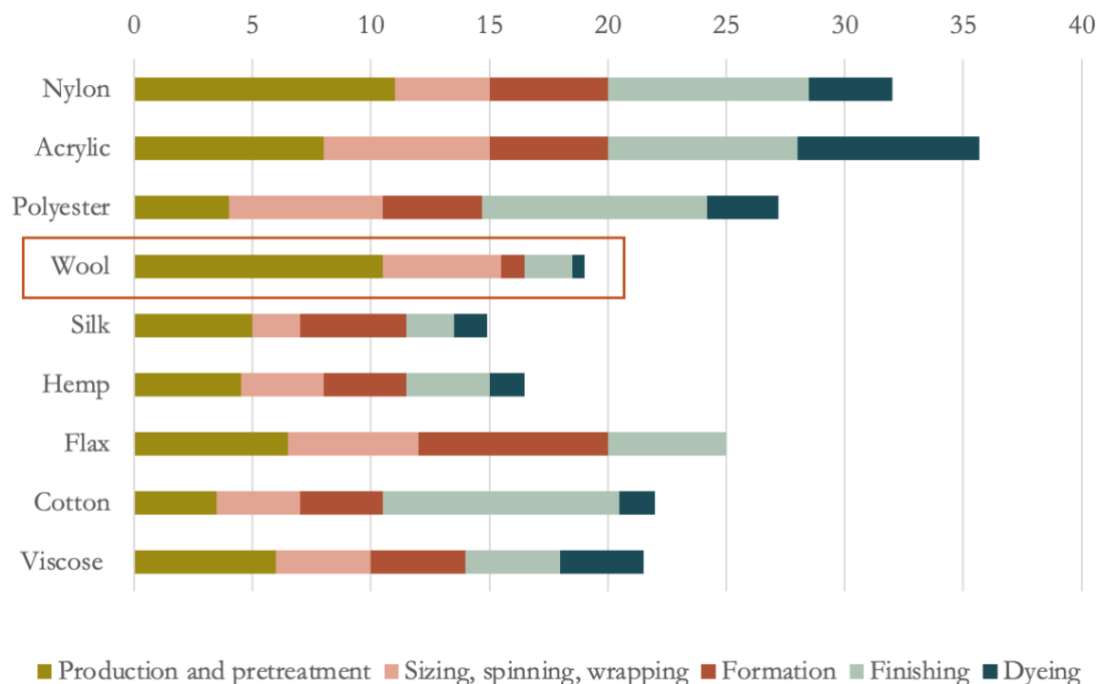


Figure 5. Carbon footprint of selected textile fibres by production stage, expressed as kg CO₂-equivalent per kg fibre. Adapted from Beton et al. (2014) and Sovbetov (2025).

Wool valorisation is also constrained by **structural barriers**, particularly those related to infrastructure and logistics. Across Europe, domestic processing capacity is declining. A recurring theme in the literature is the presence of a “missing middle”, referring to the lack of intermediate activities and infrastructure needed to move wool from farms onto the market. This includes collection, sorting, and scouring, with scouring often identified as a critical bottleneck (Klepp & Tobiasson, 2022; Špinková, 2025). For example, even in relatively well-organised systems such as Norway, wool often requires washing abroad due to insufficient domestic capacity (Hebrok et al., 2012). In other regions, Sicily faces logistical complications due to the absence of local collection centres combined with the spatial dispersion of farms (Parlato et al., 2022). The lack of infrastructure and collection systems limits economies of scale and reduces the feasibility of local value creation.

Institutional barriers are equally important. Weak coordination among actors across the value chain and a lack of intermediary organisations hinder the development of wool systems (Van Acker et al., 2023). At the European scale, differences among regions and sectors make it difficult to create a shared market structure and infrastructure (EU CAP Network, 2025). As a result, actors commonly operate in isolation, with limited capacity to organise market development collectively.

Furthermore, policy-related barriers play a part in the marginalisation of wool. Since the 19th century, European agricultural policies have begun to prioritise meat and dairy production (Špinková, 2025; Vičiūnaitė, 2020). While some regional development policies reference traditional crafts and cultural heritage, wool is rarely the focus of targeted support measures (Lennon, 2017; Špinková, 2025). This policy orientation creates a structural disincentive for farmers to invest in wool quality or processing (Vičiūnaitė, 2020). In some cases, existing policy instruments may even reinforce these challenges. For example, Norwegian standards provide higher payments and subsidies for white wool, while pigmented and coarser fibres are downgraded or excluded from subsidy schemes completely (Lennon, 2017).

Finally, **regulatory requirements** may unintentionally complicate wool valorisation. Under Regulation (EC) No 1069/2009, raw wool is classified as a Category 3 animal by-product, which is considered low risk but remains subject to rules on handling, transport, processing, and traceability. This places wool within the same broad regulatory category as other risky animal-derived materials, including hides, skins, feathers, blood, bones, horns, and others. Copa-Cogeca, the European organisation representing farmers and agricultural cooperatives, argues that the current requirements are disproportionate to the low sanitary risk of raw wool from healthy animals and calls for a lighter regulatory approach (Copa-Cogeca, 2026). The regulation does not prohibit wool valorisation, but it requires raw wool to be channelled through compliant routes before being used or placed on the market.

Where wool is not directed towards processing or an authorised use, it then falls under the Waste Framework Directive (Directive 2008/98/EC), creating additional obligations for disposal only in specialised sites. Hebrok et al. (2012) adds that wool decomposes slowly and therefore does not meet the EU definition of compostable material. While these requirements serve to protect public and animal health, they can make it more difficult for small-scale actors to handle wool as a resource. Consequently, regulation may contribute to the loss of value by increasing the practical difficulties associated with valorisation.

Beyond waste classification, cross-border trade of wool can be further affected by regulatory requirements related to agricultural products. For example, under the Regulation (EU) 2016/429 and Regulation (EC) No 1069/2009, wool is subject to sanitary, veterinary, and traceability rules, which can complicate movement and aggregation of wool within supply chains (Axfoundation & Norion Consult, 2025). In practice, these rules do not prevent the international wool trade. Still, they can increase administrative costs and transactional complexity (Axfoundation & Norion Consult, 2025). At the same time, the continued movement of greasy wool across Europe shows that such trade remains feasible. All the Nordic countries except Iceland currently export wool to the UK for washing and further processing.

The last constraint concerns the limited scope for direct governmental support measures noted by Axfoundation & Norion Consult (2025). Under Article 107 TFEU (2016), EU state aid granted by member states is generally incompatible with the internal market where it favours certain undertakings or goods, distorts or threatens to distort competition, and affects trade between the member states. Although various forms of support remain possible by mechanisms available under the Common Agricultural Policy and rural, innovation, or environmental schemes, these rules reduce the flexibility for focused action in domestic wool sectors. Even though the direct subsidy is not the only possible pathway, in Norway, more targeted national support measures have contributed to a higher utilisation rate (Axfoundation & Norion Consult, 2025).

Taken together, these findings indicate that wool waste persists not because of a deficiency of viable applications, but because of the interplay of several broader barriers.

2.4.2 Enablers

In contrast to the amount of evidence on barriers, explicit mention of enablers for wool valorisation remains limited. Nevertheless, numerous important enablers can be identified.

At a broad level, the **transition towards a circular bioeconomy** constitutes a central enabler. European policy frameworks increasingly promote the utilisation of renewable and bio-based materials, positioning wool as a fibre that can contribute to circular material flows (A. Camilli et al., 2025; Stegmann et al., 2020). This policy orientation creates favourable conditions for the research and development (R&D) of new value chains based on underutilised biomass resources.

In parallel, **market-related enablers** are emerging, especially through the growing demand for natural, local, and traceable materials. Higher environmental awareness among both consumers and industries has renewed interest in fibres with favourable environmental profiles and increased their willingness to pay. Past the conventional market forces, Špinková (2025) demonstrates the role of cultural and artistic practices in revaluing wool in the Czech and Slovak contexts, demonstrating that value can also be created outside traditional economic structures through community-based activities.

Recent research has demonstrated wool's potential across numerous fields, showing how **technological innovation** can expand its applications beyond traditional textiles and create new opportunities for entrepreneurs, particularly for lower-grade or coarse wool that is unsuitable for textile apparel markets (A. Camilli et al., 2025; Midolo et al., 2024; Parlato et al., 2022). This shift is visible in the construction sector, where demand for bio-based insulation materials has increased (Parlato et al., 2022).

Finally, **local and regional initiatives** aiming at strengthening value chain coordination are another important enabler. Efforts to improve collection systems, develop local processing capacity, and increase collaboration among actors have been identified as main mechanisms for revitalising wool sectors (EU CAP Network, 2025; Hebrok et al., 2012; Vagnoni et al., 2016; Van Acker et al., 2023). Such initiatives can help reconnect fragmented value chains and support the development of local circular business models.

In addition, **international and cross-regional cooperation** can be notably valuable where national markets alone lack sufficient scale. British Wool provides one well-established example of an intermediary structure that aggregates wool from dispersed producers. This model is discussed in more detail in Section 2.5.2. Another identified example includes the Nordic Wool initiative, pointing to the potential for neighbouring countries to share knowledge and infrastructure (Axfoundation, 2025a), or project-based cooperation between countries in the Alpine mountain region to build on shared cultural heritage and place-based branding. Although differing in scope and structure, these initiatives generally seek to overcome fragmentation by creating common market channels for wool. For smaller wool-producing countries, such cooperative projects can provide the scale and organisational capacity that individual actors often lack, making them an important enabling factor for wool valorisation within Europe.

These enablers together indicate growing momentum for wool valorisation. However, as Vagnoni et al. (2016) emphasise, the effectiveness of developments remains strongly conditioned by existing infrastructure, actor capacity, and market maturity. Consequently, the extent to which these enablers translate into large-scale system change depends on overcoming the persistent barriers identified above.

2.5 Wool value chains

2.5.1 Value chain concept

Kaplinsky & Morris (2001) define a value chain as a sequence of activities required to transform a raw resource into a product that reaches the final user. These activities include production, processing, distribution, and end-of-life, as well as supporting activities such as R&D, logistics, and marketing, with value added at each stage. A value chain, therefore, describes how economic activities are organised around a resource and how value is created as materials move through stages (Kaplinsky & Morris, 2001).

In the case of wool, the specific pathway depends on the intended end use. The textile route provides one illustrative example because it entails several processing stages. Figure 6 shows that the value chain begins at the farm level with sheep grazing and shearing, followed by grading and sorting of the fleece, during which unsuitable strands are discarded or divided for other applications. The sorted raw wool then undergoes a sequence of processing steps, including scouring (washing), blending and dyeing if required, carding (combing the wool to separate fibres), spinning wool into yarn, and finally weaving or knitting depending on the type of fabric. The last step is fulling if needed and finishing processes, including quality control (Ngo, 2022)

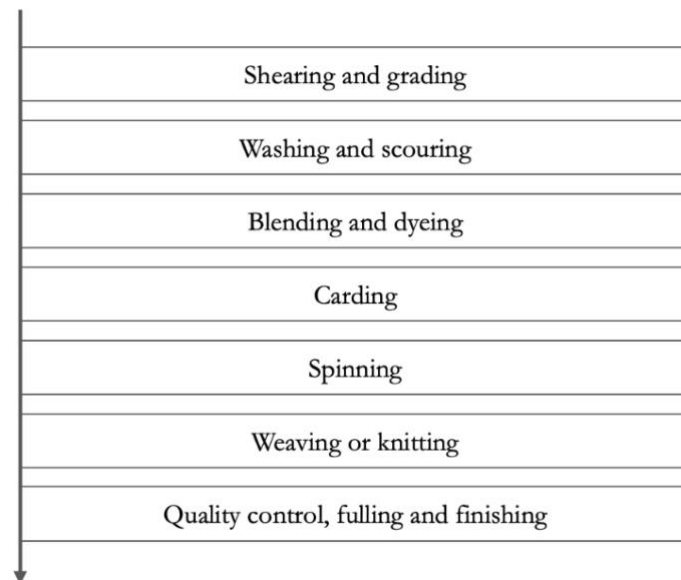


Figure 6. Wool processing steps from fleece to fabric. Adapted from Ngo (2022).

Other applications follow different and often shorter pathways. For agricultural use, wool pellets can be produced after sorting, shredding, and pelletising, during which pressure and heat bind the fibres into compact pellets. The pellets are then cooled and dried to reach a suitable moisture content (Richi, 2024).

In liquid fertiliser application, keratin in wool must first be broken down into smaller, water-soluble compounds. This can be achieved either through chemical, physical, or biological treatment, producing a nutrient-rich solution (Gaidau et al., 2021). In the case of insulation materials, Dénes et al. (2022) explain that sheep wool generally needs to be cleaned and carded before further processing. Insulation products can then be produced in several ways. Wool fibres may be bonded through wet felting, needle felting, or combined with natural or synthetic binder fibres before being thermally or mechanically formed into panels. These examples show that wool can enter several product pathways, each requiring a different set of activities to create value.

However, a value chain cannot be understood only as a sequence of processing steps. Kaplinsky and Morris (2001) also emphasise the role of multiple direct and indirect actors and the relationships between them. These actors are connected through flows of materials, information, and capital, and the chain's effective functioning depends on linkages between them. The distribution of value is further shaped by governance arrangements within the chain, as differences in market access and bargaining power can create unequal positions between actors (Kaplinsky & Morris, 2001). Identifying these linkages and power relations can help explain whose behaviour may need to change if different outcomes are to emerge. In the European wool sector, several studies also show that disruptions in such linkages limit the ability to convert raw wool into marketable products (Klepp & Tobiasson, 2022; Parlato et al., 2022).

2.5.2 Examples of integrated wool systems within Europe

While much of the literature highlights fragmentation and underutilisation in the European wool sector, several cases demonstrate that functioning wool systems are possible under certain conditions. Norway is included as an example of an institutionally embedded national system, the UK represents a well-organised collection and grading system operating at scale, and Iceland illustrates how near-complete utilisation can be achieved within a locally anchored system.

Norway

Norway represents one of the most coordinated wool systems in Europe, often cited as a benchmark for effective value chain organisation (Axfoundation & Norion Consult, 2025). Norway's system is secured through wool depots, transport arrangements, national grading standards, trained wool classifiers, farmer and shearer education, and a centralised pricing scheme (Axfoundation & Norion Consult, 2025; Klepp & Tobiasson, 2019). The foundation of the system is a long-standing state-supported wool agreement, under which sheep farmers are financially compensated for delivering wool for classification. It creates a strong and reliable incentive for farmers to participate in the formal system and has contributed to collection rates of approximately 90% of national production, with an estimated 1,300 tonnes still discarded annually (Animalia, 2026; Axfoundation & Norion Consult, 2025). The system has remained largely unchanged since the 1950s, reflecting a high degree of institutional stability.

Collection and handling are organised through a network of ten wool collection points distributed across Norway. The system is dominated by Norilia, a subsidiary of the farmer-owned cooperative Nortura, which collects approximately 75% of Norwegian wool; the remaining share is handled by Fatland Ull, a private family-owned company active in wool collection and processing (Axfoundation & Norion Consult, 2025; Hebrok et al., 2012). Thus, they are the ones who buy wool from individual farmers (Animalia, 2026). The membership organisation for sheep and goat farmers, Norsk Sau og Geit, coordinates logistics between farms and depots for a small fee (Axfoundation & Norion Consult, 2025; Norsk Sau og Geit, 2026). At the depots, wool is classified into 16 quality classes under the Norwegian Wool Standard by trained classifiers (Animalia, 2026). Farmers then receive a payment that combines the market price of the wool with a state-funded subsidy linked to the quality class assigned during grading (Hebrok et al., 2012), resulting in a combined rate ranging from approximately €1.8–€4.77 per kilogram (Axfoundation & Norion Consult, 2025). The subsidy is set annually as part of the agricultural negotiations to stabilise income and incentivise higher-quality production (Animalia, 2026). As a result, approximately 50% of the collected wool is classified as first-class, while five classes receive no subsidies and are ultimately discarded due to damaged and contaminated fibres (Animalia, 2026).

Norway has only two smaller domestic scouring facilities, and most wool is therefore sent to Haworth Scouring in the UK, in which Norilia holds a share (Axfoundation & Norion Consult, 2025; Klepp & Tobiasson, 2019). From there, approximately one-third is sold back to Norwegian producers, and the

rest is sold internationally (Animalia, 2026), where demand for first-class white wool consistently exceeds supply. Despite this level of coordination, wool is yet a by-product of meat production, and breeding for meat does not necessarily align with producing wool suitable for textile applications, suggesting that the system could be further improved by selecting optimal breeds.

The United Kingdom

The UK provides an example of a highly organised collection and marketing system operating at a large scale through British Wool. Established under the British Wool Marketing Scheme (Approval) Order in 1950, No. 1326, British Wool is responsible for collecting the wool clip from England, Scotland, Wales, and Northern Ireland, regardless of size, quality, or location, and returning market value to producers after costs. Sheep farmers with flocks above a minimum threshold are generally required to register and market their wool through this scheme. Based on the Department for Environment, Food & Rural Affairs (2023), approximately 80% of UK sheep farmers participate, delivering wool through a nationwide network of depots, drop-off points, and hauliers, densely distributed across the UK. This centralised structure helps overcome farm-level fragmentation by aggregating many small clips into commercially viable volumes for processors and exporters (Department for Environment, Food & Rural Affairs, 2023). It also enables wool to be marketed year-round rather than only during the shearing season.

British Wool occupies an unusual institutional position. It is classified as a public non-financial corporation but operates commercially and is self-funded rather than publicly subsidised. UK and devolved governments retain certain oversight responsibilities, including approval of accounts arrangements and aspects of board appointments, while British Wool maintains operational independence.

At collection centres, wool is graded into more than 100 categories and independently tested for quality by the Wool Testing Authority Europe. It is then baled into standardised lots, usually combining wool from multiple farms of a consistent type, and sold through competitive auctions to domestic and international buyers. Registered buyers attend British Wool's auctions, which are held every two to three weeks throughout the year. Wool is predominantly sold in 8-tonne lots, with up to 1,500 tonnes offered at each auction (British Wool, n.d.)

Farmers then receive a pooled seasonal payment based on the weight and average auction price of the wool grade supplied. As a result, farmers supplying similar grades receive the same price per kilogram regardless of when or where their wool is sold. This collective model reduces individual marketing risks and transaction costs and participation in these auctions has increased the payment per kilogram year-on-year. While some producers supplying higher-quality wool may be able to cover shearing costs in full and, in some cases, generate a profit, many others value the annual clip payment mainly as a way to offset part of those costs (Department for Environment, Food & Rural Affairs, 2023). Alternatively, some farmers choose to sell their wool directly to merchants, in contravention of the order.

Two major scouring plants in the UK process all types of British wool, while some finer grades are exported to a plant in the Czech Republic for specialised processing. Following scouring, British wool enters a diverse range of value chains and applications. To support these markets, British Wool's marketing strategy focuses on the storytelling of the origin of the fibre and its connection to British farming traditions and heritage. The recognisable British Wool label is applied to products that meet sourcing standards, providing buyers with confidence regarding authenticity and traceability whilst reinforcing premium positioning in the market. British Wool also provides subsidised shearing training to hundreds of people annually, supporting labour supply, animal welfare standards, as well as required fleece quality. In parallel, British Wool has invested in research and product development to expand

demand for lower-value fleeces and further promote wool as a material (Department for Environment, Food & Rural Affairs, 2023).

Iceland

Lastly, Iceland is an example of a country that has developed a highly coordinated wool system through a fully integrated domestic value chain. Wool processing has a long industrial tradition, dating back to the company Álafoss, established in 1896. Following major market disruptions in the early 1990s, Ístex replaced Álafoss in 1991 to support farmers and maintain national wool processing capacity. Since then, Ístex has been the dominant actor in the Icelandic wool sector (Rogers, 2017). Ístex operates as a shareholding company in which Icelandic farmers and associated stakeholders own more than 80% of shares (Rogers, 2017). This ownership model helps align commercial strategy with producer interests, with the value created through processing remaining within the domestic agricultural economy. Ístex purchases wool directly from farmers and processes approximately 98–99% of Iceland's annual wool clip (Rogers, 2017).

Wool is shorn twice a year, producing two distinct clips. Autumn wool is generally cleaner and of higher quality. In contrast, spring wool contains more contaminants and is more commonly used in lower-value applications such as filling materials or woven products (Ístex, 2023). Farmers undertake initial sorting by colour and quality before delivery, and the wool then gets transported to the scouring plant in Blönduós in northern Iceland, where it is further classified before washing. After washing and drying, the wool is transferred to Ístex's spinning mill in Mosfellsbær, near Reykjavík, where it is converted into yarn and finished wool products (Rogers, 2017). This model allows value creation in Iceland to go further than collection and primary processing. Rather than exporting wool mainly in raw or semi-processed form, Ístex converts it into finished products for international markets. This enables a larger share of value to be retained within the domestic wool system.

Taken together, these three examples show that functioning wool systems can take different organisational forms. Despite that, they share several core features. In all cases, wool is aggregated into larger volumes through an organised collection system, and although classification varies in complexity, some form of sorting and grading is present. Farmers are also given a clear reason to participate in the formal system: in Norway, through a state subsidy linked to wool quality; in the UK, through pooled seasonal returns from collective wool auctions; in Iceland, through a buyer that purchases the entire national clip. What appears essential is that the gap between farms and markets is institutionally organised instead of left to individual actors to solve on their own.

3 Analytical framework

Addressing the underutilisation of biological resources requires a system-level perspective, as such challenges arise from interactions between technologies, actors, markets, infrastructures, and institutions inside the broader socio-technical systems (Gottinger et al., 2025; Köhler et al., 2019). These dynamics are conceptualised as sustainability transitions (Elzen et al., 2004; Gottinger et al., 2025; Grin et al., 2011). Several frameworks have been developed to analyse such transitions, including the multi-level perspective, strategic niche management, transition management, and technological innovation systems (TIS). Because the core issue in this study is the failure to organise coordinated economic activity around an already available biological resource, the TIS framework is particularly suitable. Unlike other approaches focused primarily on macro-level regime change or niche protection, TIS emphasises the processes and conditions through which new systems of innovation and market coordination emerge.

Originally, TIS was developed to analyse the development and diffusion of specific technologies, such as solar photovoltaic systems and electric vehicles. Over time, the framework has also been applied more broadly to sustainability-oriented innovations (Gottinger et al., 2025; Markard et al., 2012). In this study, wool is therefore conceptualised as a bio-based resource around which an innovation system may develop, shifting the analytical focus from technological invention to the processes of value creation. While this represents a partial departure from traditional applications of TIS, it is in line with bioeconomy and value chain research, whereby innovation occurs through new applications and governance arrangements.

3.1 Components of the Technological Innovation System framework

The TIS framework distinguishes between structural components and system functions. Structural components in an innovation system comprise actors, networks, institutions, and physical artefacts (Andersson et al., 2023; Gottinger et al., 2025). In the Slovak wool sector, actors include farmers, processors, firms, public authorities, and intermediary organisations. Networks refer to the relationships and interactions among these actors, while institutions encompass formal regulations and informal norms, namely shared expectations that shape behaviour. Physical artefacts include infrastructure and technologies required for processing or logistics. Together, these constituents define the structural conditions within which value creation can occur.

In addition to structural components, TIS includes system functions that describe the key processes necessary for the development of an innovation system (Bergek et al., 2008; Hekkert et al., 2006; Markard et al., 2012). The performance of these functions indicates whether the system is developing in a way that supports innovation and value-chain formation, while also revealing which processes remain underdeveloped. To ensure analytical relevance, the definitions in Table 3 of the seven functions by Hekkert et al. (2006) are slightly adapted to reflect the specific context of the wool sector.

FUNCTION	INTERPRETATION OF THE FUNCTION
F1 Entrepreneurial activities	New or existing actors, taking advantage of business opportunities by experimenting with wool-based products or services.
F2 Knowledge development	Development of knowledge on how to valorise Slovak wool across different applications through research and practical experience (learning by searching and learning by doing).
F3 Knowledge diffusion	Exchange of knowledge or practical experiences among actors.
F4 Guidance of search	Processes that influence priorities within the system, including policies, visions, expectations, and strategies for wool valorisation.
F5 Market formation	Existence of demand, market channels, and creation of protected space for the formation of niche markets or temporary competitive advantage by favourable tax regimes.
F6 Resource mobilisation	Availability of resources necessary for system development, such as access to funding, infrastructure, skills, processing capacity, and material resources required for wool utilisation.
F7 Legitimation	Social and institutional acceptance of wool as a valuable resource, and whether institutions and society support its utilisation.

Table 3. *System functions and their interpretation in the context of wool valorisation. Adapted from Hekkert et al. (2006).*

3.2 Mechanism-based perspective: Barriers and enablers

While functional analysis helps identify underdeveloped or missing processes, it does not always explain their underlying causes. De Oliveira et al. (2020) therefore address this by placing greater emphasis on the structural conditions shaping function performance. They conceptualise systemic problems as weaknesses in structural components (such as actors, networks, institutions, and infrastructure) that give rise to blocking mechanisms (barriers), understood as sets of activities that hinder system functioning. Conversely, favourable structural conditions may generate inducement mechanisms (enablers), which support and strengthen system functions. For example, missing processing infrastructure may be a barrier, simultaneously constraining resource mobilisation and market formation; therefore, these functions cannot perform well. On the other hand, a strong collaboration network may enable both knowledge diffusion and entrepreneurial activities.

This approach has been further applied by Gottinger et al. (2025) in their analysis of the German bioeconomy, where they examined how the policy mix responds to structural and functional weaknesses within the Technological Innovation System. By linking the observed performance of system functions to the underlying structural conditions, they identified intervention points where adaptive policy measures could most effectively address systemic barriers. This perspective is adopted in the present thesis to identify where interventions within the system may have the greatest impact.

3.3 Motors of change

System functions are dynamic and interdependent, meaning that weakness or progress in one function can affect the performance of others over time. For example, weak knowledge development and diffusion may limit entrepreneurial activity, which, in turn, can constrain market formation and resource mobilisation. Hekkert et al. (2006) describe these reinforcing dynamics as “motors of change”, through which progress in selected functions can gradually drive wider system development. System growth, therefore, does not require all functions to improve simultaneously, but may begin through specific leverage points.

Hekkert et al. (2006) identify two motors of change, illustrated in Figure 7. Motor A is a common trigger in sustainability transitions and begins with the guidance of search (F4), in which societal problems are translated into policy goals to mitigate environmental challenges. These goals can mobilise resources, which then can stimulate knowledge creation and direct innovation efforts.

Motor B starts from entrepreneurial activities (F1), where entrepreneurs lobby for better economic conditions. They may either lobby for more resources to perform R&D or lobby for market formation to level the playing field. Either way, when markets are created, this boosts the system of entrepreneurial activity, which then leads to more knowledge creation, more experimentation, and increased lobbying for even better conditions. This perspective is particularly relevant for analysing underdeveloped sectors, as it helps identify which functions could realistically serve as starting points toward broader system development based on their function performance.

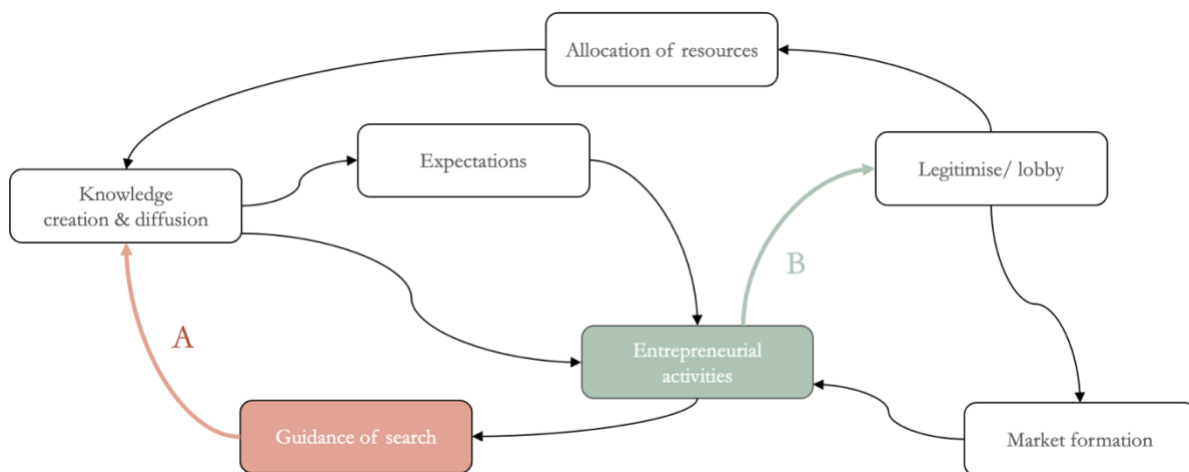


Figure 7. The logic of motors of change in a Technological Innovation System. Adapted from Hekkert et al. (2006).

4 Research design, materials and methods

4.1 Research design

The thesis adopts a qualitative single-case study design, focusing on the Slovak wool sector as the empirical case. A qualitative approach was considered most appropriate because the research intends to understand system dynamics, which cannot be meaningfully captured by quantitative indicators alone (Yin, 2003). The study is concerned not only with what is happening in the sector, but also with why these patterns persist and how they are experienced by actors involved.

In addition, a single-case study design is well-suited to examining a contemporary phenomenon in its real-life context, especially when the boundaries between the phenomenon and its surrounding context are not clearly defined (Crowe et al., 2011; Yin, 2003, p. 13). A context-sensitive design is relevant to the present study because, although the EU bioeconomy strategy applies across all member states, analysing multiple countries simultaneously risks obscuring the mechanisms functioning within specific national contexts. The use of case study methodology is also supported by the limited scholarly attention to the topic and the application of an established analytical lens in a novel context (Creswell & Creswell, 2017; Gerring, 2004; Yin, 2003).

4.1.1 Research logic

The analytical logic of the study is illustrated in Figure 8. It shows a combination of two complementary perspectives: a value chain perspective, marked as Path A in the figure, and the TIS framework, marked as Path B.

First, to address RQ1, a value chain perspective is used to examine how the Slovak wool sector is currently organised. Based on Kaplinsky and Morris (2001), the purpose of this path is to identify the chain's main structural components, including key actors, activities, material flows, bottlenecks, and points of value creation and loss in the Slovak wool sector. Based on this, an initial value chain map is developed through desk research and subsequently refined using interview data from 12 interviewees (S1–S12). This step is crucial because the Slovak wool value chain has not previously been systematically mapped in the academic literature. Since this path focuses on mapping and summarising how the Slovak wool sector is currently organised, it provides a descriptive analysis of the sector's structure. Following Sandelowski (2000), descriptive analysis aims to provide a comprehensive summary of a phenomenon in everyday terms, while remaining close to the data and observable features of the case.

Second, building on the developed value chain map from Path A, the analysis applies the TIS framework to assess the performance of the seven system functions (F1–F7). Function performance is evaluated based on the guiding questions (presented lower in this section) on a four-level scale: very weak, weak, moderate, and strong. In parallel, barriers and enablers affecting each function are identified through thematic analysis of the interview material, understood as a method for examining recurring patterns of meaning within qualitative data (Braun & Clarke, 2006). This path therefore addresses RQ2 by assessing function performance and RQ3 by explaining that performance through the barriers and enablers identified in the empirical material.

Finally, the findings from both analytical paths are synthesised to address the overall research aim of assessing how the current wool system could be strengthened to form a more functional value chain.

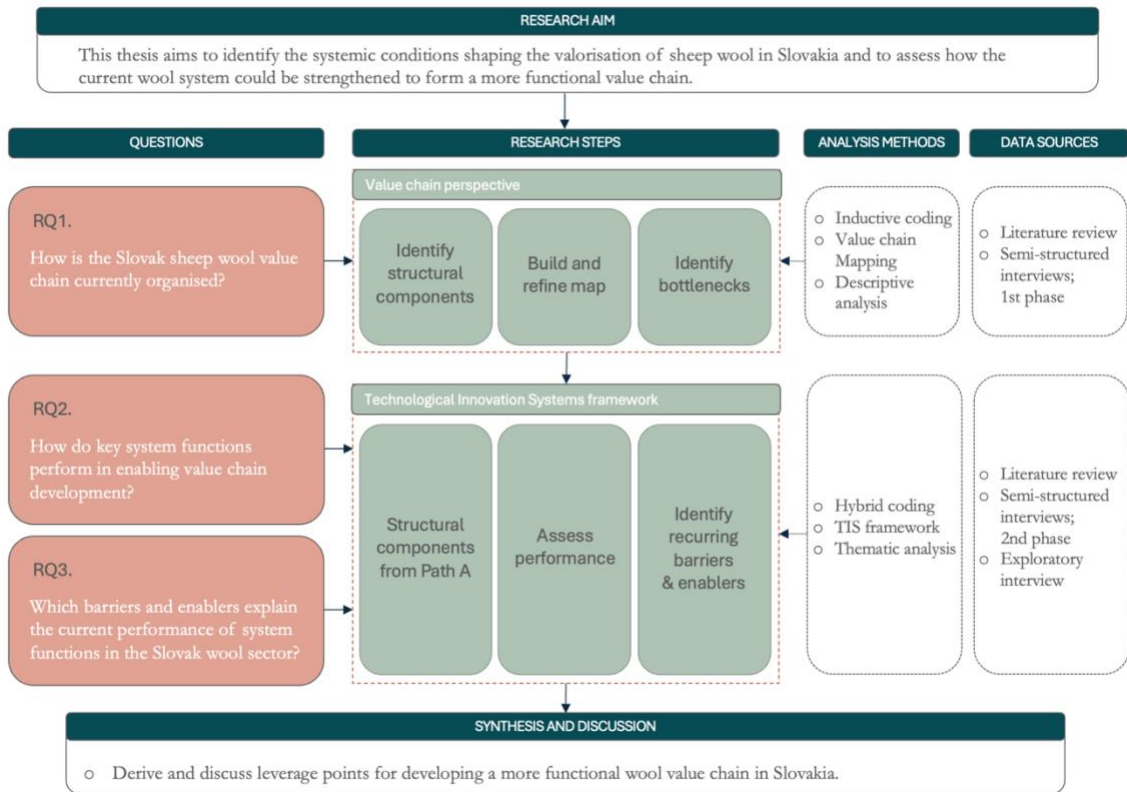


Figure 8. Analytical logic of the study.

4.2 Data collection methods

The study draws on three main sources of data. Primary data are collected through semi-structured actor interviews and an exploratory interview, while secondary data are obtained through desk research.

4.2.1 Desk research

Desk research was conducted throughout the research process to establish contextual understanding of the sector and support the interpretation of empirical findings. Prior to the interviews, this step serves several purposes. First, it provides an overview of the sector's current state in Europe. Second, it enables a preliminary mapping of actors, activities, and material flows within Slovakia's value chain. Third, the preliminary mapping informs the identification of relevant interview participants. Following the interviews, additional desk research was conducted to triangulate interview information and address remaining knowledge gaps. Given the limited existing literature on the Slovak wool value chain specifically, desk research is not treated as an independent analytical dataset but as contextual material supporting the validation of interview findings.

4.2.2 Semi-structured Interviews

Semi-structured interviews were undertaken with actors involved in the Slovak wool sector. This format allows interviewees to deviate from the interview guide and elaborate on issues that are important to them. This way, it can capture nuances that differ from the guide (Bryman, 2012). The full interview guide is provided in Appendix B. It is organised into seven thematic areas with sub-questions, designed to answer the research questions. The themes include: (1) the current wool system and value chain structure; (2) market situation; (3) perceptions and legitimacy of wool; (4) available capacity and resources; (5) knowledge development and collaborations; (6) policy and future direction; (7) broader barriers and opportunities. Core questions were asked across all interviewees to ensure

comparability, while additional role-specific questions were adapted to the respondent's primary area of activity.

Participants received the interview guide in advance of each interview. This gives respondents time to reflect on the topic and their experiences, while also serving as a reminder of the scheduled interview (Haukås & Tishakov, 2024). Sharing the questions beforehand is also intended to create clearer mutual expectations between the interviewer and participants regarding the purpose and scope of the conversation (McGrath et al., 2018). Interviews were conducted between 9. and 20. March 2026, in Slovak language, and audio-recorded with participants' consent. Twelve interviews were conducted in total, out of which six were held in person, two by telephone, and four via video call. Interviews lasted approximately 50 minutes on average.

Participants were initially identified through Naša Vlna platform, a civic initiative that connects supply- and demand-side actors in the Slovak wool sector, where actors voluntarily share contact information. Additional respondents were identified through the desk research phase and via a snowball sampling strategy, whereby existing participants recommend or introduce other potential participants who meet the study's selection criteria. Snowball sampling is considered useful in research involving limited actors, although it can also create selection bias because the sample partly depends on participants' professional and personal networks (Flick, 2022; Parker et al., 2019).

An overview of anonymised interview participants (S1–S12) across the Slovak wool value chain is presented in Figure 9. The figure distinguishes between three primary roles: primary producers (sheep farmers), market actors (businesses producing wool-based products or providing wool-related services), and intermediary actors (associations, civic initiatives, or organisations engaged in advocacy and sector development). Three respondents are involved solely in primary production, three in market activities, and one in intermediary activities. Several participants, however, performed more than one role within the wool system. Two combined intermediary and market activities, one combined primary production and market activities, and two are active across all three roles. This distribution reflects the sector's manifold nature.

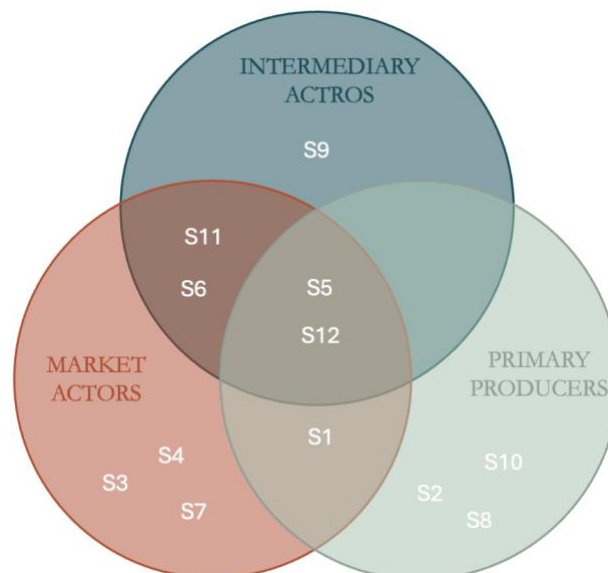


Figure 9. Interview participants (S1–S12) distinguished by the three primary roles.

4.2.3 Exploratory interview

After the semi-structured interviews were conducted, one additional exploratory interview was held with an academic actor. The purpose of this interview was to acquire insights into the analysis of the

knowledge development (F2) and knowledge diffusion (F3) functions, providing indications of how academic actors may contribute to the system. Because this interview involved a single respondent with a very specific background, the findings are based on limited evidence and are therefore interpreted with caution.

4.3 Methods used to process information

The qualitative data were then coded using Quirkos software. To address the research questions, the author used a two-layer coding scheme, based on a hybrid inductive-deductive approach. The first layer was generated inductively and captured value chain themes, including material flows, actors, and system structure, resulting in 32 coded segments. The second layer was developed deductively from the TIS framework, with main codes corresponding to the seven system functions (F1–F7) and totalling 383 segments. Within this layer, almost each data segment was further classified as either a barrier or an enabler relevant to its function, yielding 231 barrier-related and 83 enabler-related subcodes.

To answer RQ2, the evaluation criteria proposed by Hekkert et al. (2006) were translated into guiding questions adapted to the wool sector. These questions in Table 4 provided the basis for assessing the performance of each function as very weak, weak, moderate, or strong.

FUNCTION	GUIDING QUESTIONS
F1 Entrepreneurial activities	○ To what extent are actors actively engaged in utilising wool-based products or services? ○ Are entrepreneurial initiatives emerging despite challenges? ○ How diverse and widespread are these activities across the system?
F2 Knowledge development	○ To what extent are actors developing or improving processes or applications related to wool? ○ Is there evidence of efforts to build knowledge and practical skills, or is it slowly disappearing?
F3 Knowledge diffusion	○ To what extent do actors exchange knowledge or practical experiences? ○ Are networks or communication channels available to support knowledge sharing? ○ Do actors demonstrate awareness of each other's activities?
F4 Guidance of search	○ Is there a clear direction or vision for the wool sector's development? ○ Are there policies, strategies, or goals that support actor activities?
F5 Market formation	○ To what extent is there demand for wool or wool-based products? ○ Are there functioning market channels? ○ Do prices and market conditions provide sufficient incentives for actors to participate?
F6 Resource mobilisation	○ To what extent are resources (infrastructure, equipment, finances, human resources, and capacity) available? ○ Are any resource shortages constraining system development?
F7 Legitimation	○ To what extent is wool perceived by the society as a valuable and desirable material? ○ Are there positive or negative perceptions influencing its use and development? ○ Is there societal support for wool-based activities?

Table 4. Guiding questions for assessing the performance of system functions.

4.4 Limitations

The study is based on a relatively small sample of interviews compared to the national scale of the study. Although 12 interviews were carried out across several actor groups, some groups remained underrepresented. This is especially visible among farmers, of whom only three were interviewed despite the large number of sheep herd holders in Slovakia. The findings may therefore not cover the full diversity of wool-handling practices and perceptions across the national sector. In addition, participation was voluntary, creating a possible self-selection bias, as respondents may have had a stronger pre-existing interest in wool valorisation than less engaged actors. The recruitment strategy may also have favoured actors who were already visible or connected within the sector, as participants were identified partly through an existing wool initiative, web searches, and snowball sampling. More isolated or less engaged actors may therefore be underrepresented.

A further limitation concerns the type and distribution of available evidence across system functions. For example, consumer perspectives are not directly represented, which may limit the assessment of legitimisation. Similarly, guidance of search is not assessed from the perspective of institutional actors. Instead, the evaluation of system functions relies on how primary, market, and intermediary actors perceive them. While this still provides a sufficient basis for assessing the function as a whole, it means that some functions are supported by less direct evidence than others.

Lastly, the qualitative evidence is assessed using guiding questions relevant to this research design, but that don't address specific, measurable indicators. The analysis therefore does not provide a statistically representative measurement of sector performance, but it still delivers a structured diagnosis of the system functions.

5 Findings and analysis

5.1 Value chain mapping

This section answers RQ1 by presenting the current structure of the Slovak wool value chain based on insights from semi-structured interviews and additional desk research. As part of the interview, respondents were asked to describe the organisation of activities, key actors, and material flows within the system. The resulting value chain map in Figure 10 synthesises these insights and illustrates how wool moves from production to the consumer, including points of value creation and loss. The basic structure of the diagram is adapted from Van Acker et al. (2023) but has been reconfigured to reflect the specific conditions of the Slovak context. The remainder of this section unpacks the map in detail, addressing each of its components in turn: primary production, processing, downstream uses, indirect system-support actors, and a summary of the bottlenecks identified across the value chain stages.

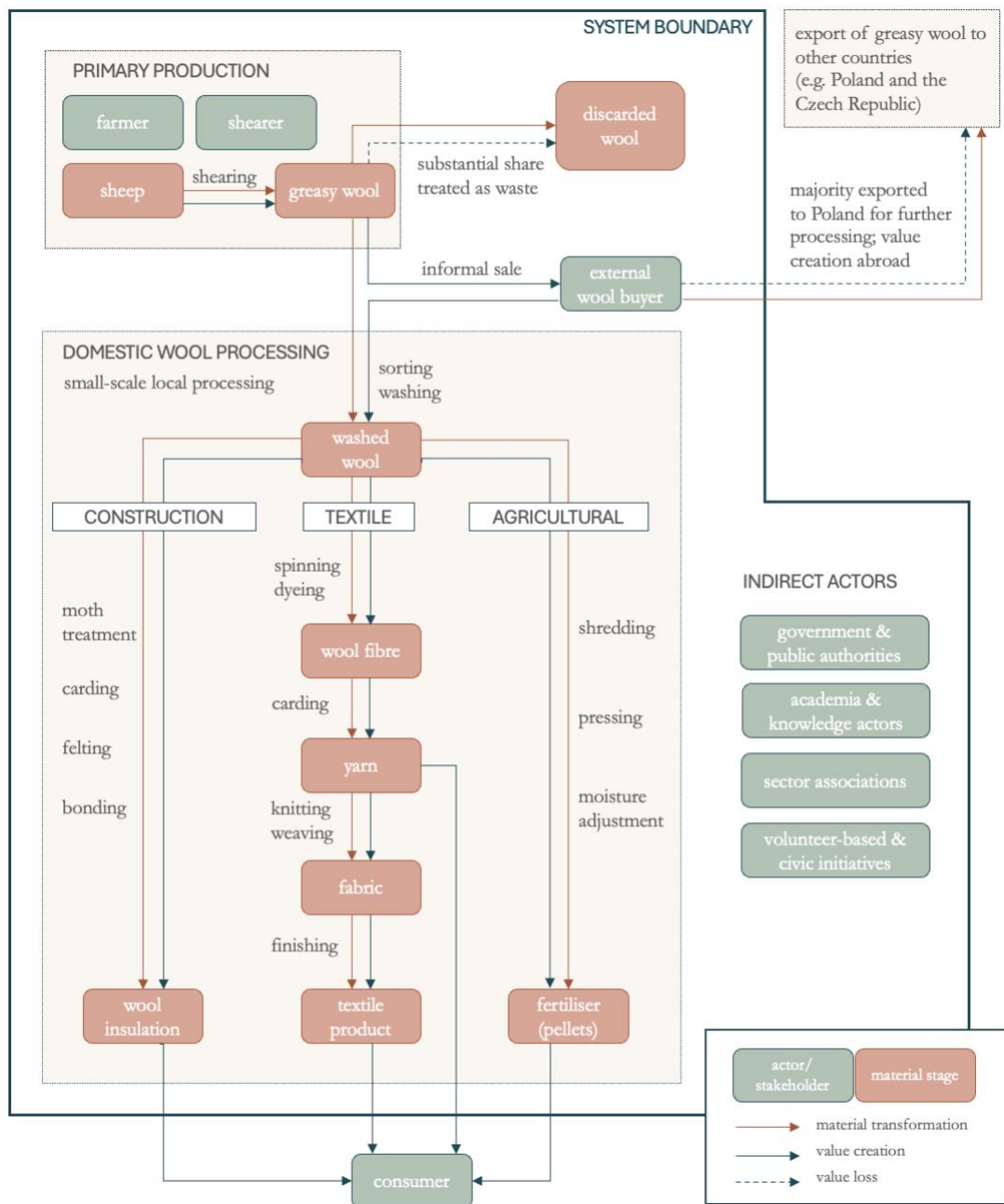


Figure 10. Current structure of the Slovak sheep wool value chain with material flows, value creation, and value loss.

5.1.1 Primary production and trade of greasy wool

Slovakia produces approximately 700 tonnes of raw wool annually (S7; S9; S11). However, as noted by S7, these figures account only for registered livestock, and the actual volume may be higher, reaching 800+ tonnes per year. Despite this continuous production, respondents consistently emphasised that only a negligible share of this wool is utilised domestically, creating a significant mismatch between resource presence and value creation. One interviewee estimated that domestic utilisation currently amounts to only tens of tonnes (S7). This estimate is consistent with the data collected through interviews and desk research, where actors were asked about their current wool-processing capacities.

The most common breeds in Slovakia include Improved Valachian and Tsigai (S3; S11). Improved Valachian produces coarser, mixed fleece that is relatively heterogeneous and better suited for non-textile or durable and technical applications. Tsigai fleece is generally of medium to coarse quality, with some variation, and can be used for a range of products, but is less suitable for next-to-skin apparel. Nevertheless, many textile brands working with Slovak wool include these types within their products (S1; S3; S5; S6; S7; S11; S12). Another frequently mentioned breed is the Slovak Merino (S3; S11), which produces fine and more uniform fleece, better aligned with conventional textile industry requirements. But also breeds such as Lacaune, which is primarily bred for milk and produces only short-length, lower-value fleece (S2; S5; S8). At the farm level, all farmers confirmed that wool is a by-product of sheep farming, with the primary economic value derived from meat and dairy production. As one respondent noted, “we do not keep sheep for wool” (S2, Farmer, March 10, 2026), reflecting wool’s weak role as a revenue stream. A reflection of that is also the overall selection of the breeds.

Farmers play a central role at this initial stage in determining whether wool retains value. One actor explained, “wool quality starts in the pasture” (S1, Market actor, March 9, 2026), pointing to the importance of on-farm handling methods, which strongly influence subsequent utilisation opportunities (S1; S5; S6; S7; S12). Contamination, primarily from plant material such as hay or thistles, can degrade wool quality and limit its prospective uses. This may occur when sheep are fed from overhead hay racks, causing hay to fall onto the back of the neck, where the highest-quality wool is often found. It can also occur when sheep graze densely overgrown pastures with thistles and lack access to shrubs against which they would naturally rub and remove the plant material. S7 also called attention to the importance of the shearing technique, in which second cuts (short fibre fragments caused by repeated clipping in the same spot) reduce fibre length and can make wool unsuitable for textile applications. Because for spinning, the fibres should preferably be at least 5–6 cm long (S7; S12).

Following shearing, wool is packed into large bags and stored on farms, sometimes for extended periods of up to a year (S2; S8; S10). During this stage, storage conditions become critical. S12 described how warm wool, sealed in bags with poor ventilation, may be ruined, whilst heat or moisture can destroy fibre quality. Wool also frequently loses value if no buyer is identified, and may ultimately be treated as waste. This stage, therefore, represents a key point of potential value loss when wool fails to enter the market channels. The fact that none of the interviewed farmers explicitly reported disposing of wool may reflect either lower trust towards the researcher and a hesitance to disclose such practices, or self-selection bias, whereby farmers with a stronger interest in wool utilisation were more likely to participate in the study. Nevertheless, the discrepancy between production volumes and observed utilisation suggests that a major share of wool is either exported or discarded. In either case, potential value creation is ultimately lost to the Slovak economy.

In cases where wool reaches a buyer, shearers frequently play an important intermediary role, informally coordinating supply and demand through personal networks (S2; S5; S8; S10; S12). When individual actors seek to buy or sell wool, they most often need to identify farmers or buyers

themselves through previously established personal contacts. This shows that the current collection and trading system is based on “I know someone who knows someone”. Almost all respondents, however, indicated that Slovak wool gets exported, primarily to Poland (S1; S2; S4; S6; S7; S8; S10; S11; S12), with smaller volumes potentially going to the Czech Republic (S1; S6; S10). Very low prices and limited transparency often characterise these transactions.

5.1.2 Processing capacity and domestic infrastructure

A critical bottleneck for Slovak wool textile producers is the absence of wool scouring (washing) facilities in Slovakia (S1; S3; S4; S6; S7; S11; S12). As one respondent stated, “We used to buy a European mix already washed, because we had nowhere to wash it ourselves” (S11, Market actor, March 18, 2026). Historically, there was a large-scale textile enterprise, Slovena in Žilina, which previously provided domestic scouring and processing capacity (S5; S11; S12). However, these facilities declined during the post-socialist restructuring period (S5), and Slovena ultimately ceased textile production in 2006 due to declining demand and increasing competition from imported textiles (Slovena, n.d.). Today, only limited industrial processing capacity remains. Facilities such as Aspera Spinn in Čadca and Poľana in Lučenec continue to operate as privately owned commercial companies (S3; S4; S6; S7; S11; S12). Their operations have significantly downsized since the socialist period, and respondents described them as technologically stagnant and increasingly marginal. As these facilities also lack scouring, they can only process already-washed wool. Production is typically organised on a commission basis, with a minimum batch of around 300 kg, a threshold often considered too high for small Slovak businesses (S1; S3; S6; S12). These facilities primarily process imported wool for foreign markets, further underpinning patterns of value creation abroad.

Respondents utilising Slovak wool, therefore, reported seeking washing capacity abroad (S1; S6; S7; S11; S12). Publicly identifiable examples include Nejdecká česárna vlny (NCV) in Nejdek, north-western Czechia, which discloses an annual processing capacity of approximately 23,000 tonnes, and Poltops in southern Poland, which publicly indicates minimum processing volumes of around 500 kg (Modiano, n.d.; Poltops, n.d.). Such thresholds may again prove too high for Slovak textile brands seeking only limited batches of local wool. Reflecting this constraint, two respondents working in the textile sector described attempts to explore cooperation with a Slovak insulation producer, testing whether the producer's washing process could meet textile-quality standards and open up a new domestic processing route (S6; S12).

At a smaller scale, Vlnárska Manufaktúra has been established in Senec as the first Slovak wool mini-mill. It enabled local farmers, designers, and small businesses to access domestically processed material from as little as 1 kg. Several respondents reported using this company's services (S1; S2; S4; S5; S6; S12). However, its capacity remains limited (approximately 2 tonnes per year), and it currently cannot meet the growing demand for wool processing. Importantly, the facility also utilises lower-quality wool residues to produce agricultural pellets, demonstrating cascading use and full material utilisation.

This evidence indicates that the critical infrastructural gap in Slovakia is not the complete absence of processing facilities, but rather the lack of medium-scale scouring capacity capable of serving volumes beyond niche batches while remaining accessible to domestic actors. In this sense, a medium-scale washing facility appears to represent one of the most important missing links in the current value chain, specifically for actors operating in the textile sector.

5.1.3 Downstream uses

Further down the value chain, a small number of textile brands can fully utilise Slovak wool in their products. These include Gubaňa (knitwear), Mokoša, and Evucha (yarn producers). Alongside, several smaller producers (including artisans and artists) combine Slovak with imported wool to preserve continuity of supply. As the respondent noted, “local wool is difficult to obtain consistently in

sufficient quality and volume” (S3, Market actor, March 12, 2026). All these actors, whether fully or partially working with Slovak wool, contribute to domestic value creation but operate at a limited scale.

Beyond textiles, some companies are working with alternative applications. Deamwool, Isowool, and Wool Style produce thermal and acoustic insulation materials for the construction sector. One actor noted that customers are actively seeking wool-based insulations, especially for renovations of older houses (S11). These applications have the potential to utilise coarser, lower-grade wool on a large scale. From publicly available information, Isowool handles approximately 25–30 tonnes of wool annually (Isowool, n.d.).

Among these actors, Wool Style appears to be one of the most expansion-oriented. The company has reportedly processed around 30 tonnes of wool annually, but states that it is preparing to open a new wool-processing facility with an estimated annual capacity of approximately 600 tonnes, in addition to producing rigid insulation boards. Initial throughput is expected to remain lower at the beginning while raw material sourcing and technological processes stabilise. According to the company, around 400 tonnes of wool could later be directed to the construction sector, while coarser grades may be used in agriculture and finer fibres in textiles. The owner explained that it remains unclear whether the new facility will include wool-scouring capacity from the outset or whether this will be developed separately through a future collaborative project.

Finally, only one company, Rokosan, was identified as producing organic amino-acid liquid fertiliser. According to publicly available sources, the company was planning to utilise the entire Slovak wool production of 700 tons, with additional imports from other countries (Slovenská televízia a rozhlas, 2023). While some respondents reported past or likely collaboration with the company, others described it as currently inactive within the Slovak wool value chain. The company did not respond to requests for clarification, and a recent news article suggests that the initiative has struggled to establish a viable market for this product due to low demand (Lászlóová, 2025).

Taken together, these cases suggest that higher-volume applications for Slovak wool are possible, particularly in construction and agriculture. However, they also reinforce the point that ambitious production plans alone are not sufficient. Whether Slovak wool can reliably supply such capacities will depend on stronger coordination among actors, as current collection and logistics systems continue to be underdeveloped. If sufficient volumes cannot be sourced domestically, processors may need to obtain additional wool from international suppliers, even where the original intention was to use domestic wool.

5.1.4 Indirect actors and system support

In addition to actors directly involved in material flows, a range of indirect actors influence the functioning and development of the Slovak wool value chain. These include government institutions (e.g. Ministry of Agriculture and Rural Development (MPRV SR), Agricultural Paying Agency (PPA)), sectoral associations (e.g. Slovak Sheep and Goat Breeders Association (ZCHOK), Slovak Association of Young Framers (ZMF)), academic institutions and knowledge support organisations (e.g. Institute of Agricultural Knowledge and Innovation (IZPI), Slovak University of Agriculture in Nitra (SPU), Slovak Academy of Sciences (SAV), and The Centre for Folk Art Production (ÚEUV)), and volunteer-based initiatives (e.g. civic initiatives OZ Naša vlna and OZ Chováme doma).

Across interviews, government actors are consistently described as largely absent from the wool sector (S1; S3; S4; S5; S6; S7; S11; S12), despite their indirect influence through agricultural policy which includes financial support for sheep farmers through per-animal payments and land-size payments. At the same time, the state has substantial capacity to set the wool sector's strategy and direction. Even

without the provision of targeted support measures, simply signalling strategic importance could encourage other actors to engage.

In addition, sectoral organisations, such as farmer associations, are present within the wool system and perform several supporting functions, including advocacy, representation, the provision of sectoral data, facilitation of knowledge exchange, and efforts to connect actors and support market functioning, for example, by helping farmers sell products (S1; S9; S10; S11). However, their practical impact is perceived as limited, with a gap between stated objectives and concrete results (S5). Efforts to build networks or strategy remain slow and incremental, constrained by limited resources and weak institutional support (S11). In terms of power relations, these organisations occupy a mediating but relatively weak position. Although they hold potential lobbying power, they currently lack the authority and capacity to translate this into successful coordination of the system (S5). Taken together, interviewees suggested that Slovak Sheep and Goat Breeders Association (ZCHOK) could assume a more central coordinating role within the Slovak wool sector. Realising this potential, however, would likely require stronger state backing and additional resources.

Furthermore, knowledge support organisations are also structurally present, but do not appear to be visible to the interviewees. Very few respondents referred to these actors in connection with general agricultural education, research, cultural activities, or advisory support (S2). The specific functions of these institutions differ. The Institute of Knowledge and Innovation in Agriculture (IZPI) represents the agricultural advisory and knowledge-transfer infrastructure in Slovakia. Its activities include lifelong education, training and certification of agricultural advisors, information services, and support for knowledge exchange among agricultural actors. In the context of the wool value chain, such an institution could potentially contribute to improving farmers' access to information on sheep production, wool quality management, or opportunities for diversification.

Similarly, the Slovak University of Agriculture in Nitra (SPU) represents a formal research and education actor within the agricultural knowledge system. Through its teaching and research activities across fields, SPU has the potential to contribute scientific knowledge and skills development relevant to the sector. The Slovak Academy of Sciences (SAV) represents a broader research infrastructure that could support knowledge creation through interdisciplinary research.

In contrast, The Centre for Folk Art Production (ÚĽUV) occupies a different role as a cultural and craft-oriented knowledge actor. ÚĽUV primarily contributes to the preservation and development of traditional craft skills, supports craft practitioners, and promotes the cultural value of handmade products. Given wool's historical connection to traditional textile practices in Slovakia, ÚĽUV represents an important actor for maintaining cultural knowledge and supporting value creation through artisan production.

However, despite the potential relevance of these organisations as knowledge and cultural support actors, respondents identified no substantial role for these institutions in transforming the system. Their limited involvement suggests a weak connection between existing knowledge infrastructures and value chain actors, potentially constraining knowledge exchange and the development of new wool-related activities.

In contrast to formal institutions, grassroots initiatives such as OZ Naša Vlna, OZ Chováme Doma and similar projects are consistently described as active and visible within the system. Their primary roles include awareness-raising and community-building (S5; S3; S7). These initiatives contribute to the cultural revalorisation of wool and help reconnect consumers and producers with the material. However, as they present bottom-up development, their impact is constrained (S5). While they demonstrate alternative pathways and exert cultural and symbolic power, they operate in isolation from broader institutional support.

5.1.5 Summary of identified value chain bottlenecks

Table 5 summarises the identified bottlenecks and their consequences across the Slovak wool value chain, by stage:

STAGE	MAIN BOTTLENECKS	CONSEQUENCES
Primary production	Weak incentives for quality improvements Dispersed small wool volumes	Quality is inconsistent for higher value uses, and supply mobilisation is weak.
Collection & trade	No formal collection system No wool grading system Low price transparency	Reliance on informal networks to sell/buy wool, where farmers face weak bargaining power and often accept very low prices or barter.
Processing	No domestic scouring facility Textile processing capacity does not match the domestic actors needs	Dependence on foreign facilities for scouring or processing and exports shifting value creation outside the country.
Downstream markets	Small, fragmented domestic demand Irregular and unreliable supply	Wool businesses struggle to scale production and secure consistent inputs.
System support	No clear coordinating body Difficult access to support schemes Weak wool-specific advisory	Actors operate in isolation without guidance and opportunities for sector development are underutilised.

Table 5. Summary of main bottlenecks by value chain stage.

5.2 The performance of system functions

As previously mentioned, the TIS framework identifies seven system functions that describe the key processes required for the development of an innovation system (Bergek et al., 2008; Hekkert et al., 2006; Markard et al., 2012). The analysis addresses RQ2 by assessing the performance of system functions, and RQ3 by identifying the underlying barriers and enablers that explain this performance.

F1 Entrepreneurial activities

- To what extent are actors actively engaged in utilising wool-based products or services?
- Are entrepreneurial initiatives emerging despite challenges?
- How diverse and widespread are these activities across the system?

There is evidence that actors are actively developing and utilising wool-based products and services, as described in Section 5.1.3 above. At the same time, several respondents pointed out ongoing experimentation and attempts to develop new uses and value creation for wool, even in the absence of sufficient system structure (S1; S3; S4; S6; S7; S11; S12). As one respondent described the system, progress is happening and “slowly, slowly the circle is getting stronger” (S12, Market actor, March 20, 2026). This suggests the presence of multiple small-scale entrepreneurial initiatives driven by individual actors and enterprises.

However, these activities are neither widespread nor coordinated at the system level. Respondents consistently emphasised that entrepreneurial initiatives remain fragmented and small in scale (S1; S3;

S4; S10; S11). Many of these businesses had to downsize or are still in the early stages of experimentation, while others continue to search for stable processing facilities or a reliable wool supply and have therefore not yet developed into economically viable business operations. Several respondents within the textile sector also expressed uncertainty regarding the future, with many describing themselves as driven more by personal commitment and passion than by clear economic viability. As one interviewee described, “I do it so that people around me can sit at a spinning wheel and enjoy it too” (S5, Market actor, March 18, 2026).

The picture becomes somewhat broader when considered relative to the total domestic wool supply. Small textile entrepreneurs have the capacity to utilise only a minor share. At the same time, actors in the construction and agricultural sectors appear to have a huge potential to utilise even the full domestic supply. Although this potential is not currently realised, its existence indicates that the principal challenge is less in the absence of entrepreneurial activity than in enabling entrepreneurs to access available wool resources in a consistent way. Respondents confirmed this by reporting that a stable supply remains the main obstacle, not the lack of applications. Therefore, the performance of entrepreneurial activities (F1) is assessed as weak to moderate, with emerging potential.

F2 Knowledge development

- To what extent are actors developing or improving processes or applications related to wool?
- Is there evidence of efforts to build knowledge and practical skills, or is it slowly disappearing?

As stated previously, market actors within the Slovak wool sector are engaged in developing and improving processes and applications. Interview data indicate experimentation, particularly in the construction sector. Examples include the development of alternative moth-treatment processes that avoid biocidal products restricted under EU regulation, as well as the testing of new technologies for more optimal processing (S2; S7; S11).

The wider development of knowledge and hands-on skills is generated primarily through self-learning (trial-and-error), long-term accumulated practical experience, and intergenerational transfer of knowledge within sheep farming, rather than by structured institutional support (S6; S7; S10; S11). At the same time, respondents reported a general lack of accessible information and training, particularly for farmers, many of whom lack knowledge of how to handle wool to increase its value (S4; S6; S12). Respondents feel that vocational schools in Slovakia provide limited education in processing technologies (S3; S10) and the sector overall faces a shortage of skilled labour, especially in areas such as sheep farming and wool processing (S4; S6; S7; S10; S11). As one person noted, “the people have lost those skills” (S10, Farmer, March 17, 2026).

The exploratory interview uncovered an academic involvement related to the development of knowledge through research and publications in the field of ethnological expertise on traditional material culture and wool-processing practices. Moreover, wool-related research is likely taking place in other fields, such as agriculture, technology, materials science, or environmental science, but this was the only example identified within the scope of the study.

Overall, while some knowledge development activities are present, they stay mostly practice-based and isolated. In some areas, knowledge is not only underdeveloped but also declining. Basic information is also lacking at the national level, including guidance on fleece types, proper wool handling methods for farmers, and processing requirements, even though research may be underway in the background. Therefore, knowledge development (F2) is assessed as weak within the system.

F3 Knowledge diffusion

- To what extent do actors exchange knowledge or experiences?
- Are networks or communication channels available to support knowledge sharing?
- Do actors demonstrate awareness of each other's activities?

Knowledge exchange between actors does occur only to some extent. It is primarily based on personal contacts where actors exchange experiences within their immediate circles (S4; S6; S11; S12). Respondents also suggested that actors often do not know where capacities or opportunities exist across the system.

It is important to note that a few respondents mentioned previous cooperation of knowledge exchange with Czech and Norwegian programmes or suggested that some collaboration may exist among academia and organisations or initiatives linked to the wool sector. However, respondents generally reported weak cooperation between organisations and research institutions (S6; S11). The exploratory interview illustrated a formal collaboration between an academic researcher and the ÚEUV centre. This cooperation involves disseminating knowledge on wool-processing practices through research publications, commercial books, and public speaking at events.

Formal networks and communication channels also exist, but they primarily serve broader agricultural support. The ZCHOK association fulfils an important coordinating role within the sheep sector, with notable potential to connect actors. However, its activities are focused mainly on breeding, livestock management, and meat and dairy production, rather than wool-related issues. Likewise, institutions such as IZPI provide training and advisory services for agricultural actors, but no focus on wool-related knowledge transfer was identified by either interviewees or additional desk research (S5; S6; S7; S12).

Some bottom-up initiatives help improve knowledge diffusion. For example, OZ Naša vlna facilitates networking and workshops, but those are primarily designed for wool artisans. As one respondent described, these projects “bring people together, build awareness, and build community” (S4, Market actor, March 16, 2026). The larger picture, therefore, reveals weak connections and knowledge diffusion across the sector. Actors commonly lack knowledge about where to access training or support, and farmers frequently do not know where to find buyers for their wool. In addition, no central platform or mechanism for systematic information exchange around wool currently exists, and the reach of existing initiatives remains limited. If this function were assessed bottom-up, it would be moderate owing to the efforts of community-building and knowledge-sharing from smaller initiatives such as Naša Vlna and ÚEUV. However, since the top-down approach would have a greater reach and greater power for change, knowledge diffusion (F3) in the Slovak wool sector can be characterised as weak.

F4 Guidance of search

- Is there a clear direction or vision for the wool sector's development?
- Are there policies, strategies, or goals that support actor activities?

Interview data suggest that the Slovak wool sector lacks a clear strategic direction from the top down. Wool stays a low policy priority and appears only rarely in political discourse, without translating into concrete action (S1; S2; S6; S8; S9). This is reflected in weak institutional and policy support: there are no targeted programmes or clearly mandated responsibilities, while existing subsidies remain focused on livestock production more broadly (S2; S4; S7; S9). Moreover, government influence was also

discussed as a source of additional pressure. Several interviewees referred to rising costs and administrative burdens, citing new financial obligations and transaction-related taxes, which they viewed as almost liquidating for some small businesses (S3; S6; S7; S11). As one interviewee described it, “They do not need to support us, but they could at least stop throwing obstacles in our way” (S3, Market actor, March 12, 2026).

Although respondents perceive public support for wool-related activities as limited, triangulation fairly quickly showed that formal funding instruments do exist. For example, Pôdohospodárska platobná agentúra (Agricultural Paying Agency) (2026) released Call 6/SP/2026-73.7 under the CAP Strategic Plan 2023–2027, which supports investments to expand processing capacities in the agri-food sector. While the call is not specifically designed for wool, its definition of livestock processing explicitly includes wool among the listed examples. Nevertheless, respondents emphasised that such calls and funds are often difficult to identify and administratively complex to apply for, particularly for actors with lower familiarity with bureaucratic application procedures (S3; S6; S7; S11). Some also questioned the transparency of the selection process and pointed to the lack of feedback after an unsuccessful application, which limits their ability to improve future submissions. The problem is therefore not only one of funding provision, but also of guidance to help actors navigate and make use of available opportunities. The state appears largely passive while holding a significant capacity to enable the system.

In the absence of strong top-down direction, some efforts to create direction emerge from the bottom up through farmer associations and civic organisations. However, these plans remain difficult to sustain without cooperation between them and human and financial resources (S11; S12). As a result, they often reach only small groups of actors and struggle to generate wider change. Overall, the guidance of search function (F4) remains very weak, with actors operating in a context characterised by uncertainty.

F5 Market formation

- To what extent is there demand for wool or wool-based products?
- Are there functioning market channels?
- Do prices and market conditions provide sufficient incentives for actors to participate?

All farmers confirmed that demand for domestic wool is minimal (S2; S8; S10). This is reflected in extremely low purchase prices, sometimes as low as €0.10 per kilogram, which do not come anywhere close to covering the cost of shearing (S2; S8; S9). Price formation is inconsistent and largely dictated by buyers, revealing a clear power asymmetry. Farmers have little bargaining power and often accept “whatever price is offered” (S2, Farmer, March 10, 2026), as the alternative is to incur disposal costs (S2; S10). In some cases, transactions take the form of barter exchanges, such as wool traded for rock salt (S2; S9). Only a small number of farmers are in a position to choose between several buyers.

A recurring theme is the existence of a “vicious cycle” which one respondent described as “Low demand leads to low prices, which discourages farmers from committing resources to quality improvements, resulting in low-quality wool that further limits market demand” (S12, Market actor, March 20, 2026). Interview participants from the wool-processing side noted that they cannot simply pay higher prices for completely unsorted wool, as a significant share of impurities and damaged fibres must be removed during sorting. As one actor demonstrated, only around half of the original wool weight remains usable after sorting and washing, and because of that, processors are unwilling to pay a higher price (e.g., €0.50 per kilogram) to farmers (S11). Still, willingness to pay depends strongly on the intended use of the wool. Actors in the textile sector indicated they would pay €1–€3 per kilogram for well-cut and sorted wool, depending on its properties (S5; S6; S7; S12). Another respondent

suggested that if basic quality standards were met, reaching €0.60 per kilogram would already represent a major improvement for farmers (S11).

The absence of stable and functioning market channels further limits system development. There is currently no structured domestic market for wool, and transactions commonly occur informally through occasional buyers, such as Polish traders. Actors repeatedly pointed to the lack of a centralised purchasing system or intermediary that would connect farmers with processors (S1; S4; S11; S12). The absence creates a situation where processors struggle to access wool while farmers are unable to sell it. Therefore, market formation (F5) is assessed as weak but emerging. It is considered emerging because increasing interest from the construction sector, and price premiums for sorted higher-quality wool indicate the early development of new market opportunities.

F6 Resource mobilisation

- To what extent are resources available?
(resources include: infrastructure, equipment, finances, human resources, and capacity)
- Are any resource shortages constraining system development?

Actors reported major resource-related challenges across all stages of the wool value chain, from production to processing (S6; S11; S12). Although sufficient quantities of wool are currently available in Slovakia, its potential as a resource is only partially realised. Respondents noted that wool is often poorly handled at the farm level, thereby reducing its quality and limiting its suitability for higher-value textile applications. However, farmers indicated that improving quality at the farm level requires extra labour and time, which is ultimately a financial constraint (S6; S12). In addition, there is a general shortage of shearers, whose services are now becoming increasingly expensive (S8).

Since the estimated 700 tonnes of wool production in Slovakia is distributed across around 9,000 holdings (Plemenárske služby SR (PSSR), 2025), effective mobilisation of this resource depends on mechanisms that can bring the dispersed wool supply together. Farmers viewed a collection centre as beneficial because it would give clarity on where wool could always be delivered (S2; S8; S10). Market actors, in turn, would no longer need to source each batch individually, which respondents described as time-consuming and inefficient (S4; S8; S10). However, collection centres would require not only physical infrastructure, but also specialised knowledge and experience. As respondents explained, sorting wool is not simply a matter of separating clean from dirty material. It involves assessing fibre length, elasticity, breed type, and other quality parameters. This expertise is scarce and cannot easily be replaced by untrained labour (S7). Resource mobilisation, therefore, also depends on the human competencies needed to classify and allocate wool to appropriate uses.

Beyond collection and sorting, respondents also highlighted the lack of medium-scale processing capacity and textile-quality scouring infrastructure. As explained in Section 5.1.2, existing processing facilities are either too small (Vlnárska Manufaktúra, with a maximum capacity of 2 tonnes per year), or too large (Poľana, which requires a minimum batch volume of 300 kg). This leaves a gap in medium-scale processing suitable for many actors (S4; S6; S7; S12). The absence of a dedicated textile-quality scouring facility now increases reliance upon foreign processing or on domestic washing facilities built for construction wool, where textile-quality output is currently insufficient (S1; S2; S11).

All of the mentioned constraints are closely linked to financial resources. Large-scale investments in processing and logistics infrastructure require substantial capital beyond the reach of most actors (S9; S11). While some actors have accessed EU funding and invested in technology, these cases remain very few, and most respondents point to the state support as necessary for wider development (S1; S2; S3; S4; S6; S7; S9; S10; S11).

Broader structural trends in sheep farming and agriculture may further intensify existing resource constraints. Eurostat data indicate that more than 46% of farms in Slovakia are managed by farmers aged over 55, suggesting an ageing agricultural workforce (Eurostat, 2020). This may contribute to future labour shortages and the potential loss of practical knowledge. In some cases, it may also reduce farmers' willingness or capacity to adopt new practices. At the same time, the longstanding trend of declining sheep numbers raises concerns about the long-term resource availability. Even if processing capacity grew, some actors questioned whether the current scale of primary wool production would be sufficient to sustain large industrial operations (S10). One respondent argued that “before a new industry could emerge, sheep numbers would first need to increase” (S3, Market actor, March 12, 2026), which they considered unlikely under current trends.

The resource mobilisation (F6) function is more difficult to assess, as it encompasses many aspects that fall under this category. The Slovak wool sector has more than enough material resources in its current structure, but its mobilisation is unrealised efficiently due to limited capacity to transform dispersed wool of variable qualities into a usable input for different buyers. These constraints also vary across sectors: textile actors struggle to secure higher-quality wool and suitable processing facilities for smaller batches; construction and agricultural applications encounter the logistical challenge of aggregating sufficient volumes, but more often own and operate production lines; farmers, in turn, are particularly constrained by labour shortages and the costs of improving wool quality. Nevertheless, the absence of dedicated financial support, scouring facilities, and a collection centre constitutes a shared constraint across all. For all these reasons, resource mobilisation (F6) is assessed as weak to moderate.

F7 Legitimation

- To what extent is wool perceived as a valuable and desirable material?
- Are there positive or negative perceptions influencing its use and development?
- Is there societal support for wool-based activities?

Evidence from the interviews suggests a mixed picture for this function. On one hand, a relatively high level of legitimation exists among the interviewed actors and their network, which was to be expected given their direct involvement and interest in the topic. Beyond this group, legitimation remains limited. As previously mentioned, wool is not considered a policy priority and therefore lacks recognition among key decision-makers with the power to influence sector development. Similarly, many farmers continue to perceive wool primarily as a waste material (S2; S6; S7; S8; S9; S12).

At the social level, wool has largely lost its cultural meaning, and awareness of its value generally remains low (S1; S5; S11). Although respondents observed a growing group of environmentally conscious consumers interested in natural and locally sourced products, one respondent described this customer base as “a very narrow group” (S4, Market actor, March 16, 2026). In general, price still often outweighs sustainability considerations (S1; S10; S12), a tendency reinforced by the widespread availability of inexpensive fast fashion and synthetic alternatives (S3; S6; S7). Persistent negative perceptions of Slovak wool as rough or uncomfortable also continue to hinder its acceptance, particularly in clothing applications (S1; S6; S12). One actor in the textile sector, therefore, pointed to the importance of intermediaries, such as yarn retailers, in communicating the value of Slovak wool and connecting it to consumers (S6). On the other hand, in construction applications, one respondent noted strong customer interest in healthier homes.

Overall, legitimation (F7) within the Slovak wool innovation system remains weak but is emerging, with gradual signs of improvement. Wool is gaining recognition within a small circle but needs to spread widely among farmers, policymakers, and society. As one respondent put it, “people need to start seeing wool not as waste, but as a raw material” (S12, Market actor, March 20, 2026).

Summary of system function performance

Table 6 summarises the assessment value of each system function (very weak, weak, moderate, and strong) in the Slovak wool sector, together with the identified barriers and enablers that justify this assessment value.

FUNCTION	VALUE	MAIN BARRIERS	MAIN ENABLERS
F1 Entrepreneurial activities	Weak/ moderate (emerging)	Small-scale initiatives Uncertain profitability Unreliable supply	Motivated actors Niche initiatives Raw wool availability
F2 Knowledge development	Weak	Limited training Weak academia links Shortage of expertise Declining know-how	Isolated research Practical experimentation and self-learning
F3 Knowledge diffusion	Weak	Personal networks only No central platform Weak cooperation Limited advisory support	Informal exchanges Naša vlna and ÚEUV community events
F4 Guidance of search	Very weak	No strategy Low policy priority Weak leadership Limited cooperation capacity	Existing individual initiatives and associations EU circular bioeconomy momentum
F5 Market formation	Weak (emerging)	Vicious cycle No structured market Weak demand Low prices	Emerging niche textile demand High demand in the construction sector Price premiums for sorted wool
F6 Resource mobilisation	Weak/ moderate	Missing infrastructure Dispersed wool supply Labour shortages Weak financial access	Available wool volumes Available EU funding Adaptive firms
F7 Legitimation	Weak (emerging)	Wool is seen as waste/rough Low awareness Cheap substitutes	Interest in local/natural materials Expanding construction uses Committed wool advocates

Table 6. Summary of the system function performance together with the main barriers and enablers.

6 Discussion

6.1 Why does a resource not become a resource?

The evidence confirms that the challenges facing Slovak wool are not primarily rooted in the material properties of wool itself. As argued by Rajabinejad et al. (2019) and echoed by interviewees, all wool types of varying qualities can be utilised when aligned with appropriate end uses. Therefore, the core constraint is truly connected to a systemic failure. A more specific question is where, within the Slovak wool system, the main constraints lie, and why wool consistently fails to function as a viable resource.

Overall, the barriers identified in the European literature in Section 2.4.1 broadly match those found in this study, although not all appear with the same intensity. While the previous section discussed barriers separately in relation to individual system functions, three wider patterns emerge as particularly influential in explaining the weak performance of the Slovak wool system as a whole and directly address RQ3. First, the sector is highly fragmented across all stages of the value chain. Second, it is trapped in a “vicious” cycle of low demand, low prices, and limited incentives for quality improvement or investment. Third, the absence of a coordinating body or institutional framework weakens actors' alignment and their collective ability to maximise total value. All three patterns are discussed in more detail in the sections below.

6.1.1 Fragmentation

Fragmentation may be described as “the physical separation of different parts of a process” (Gereffi et al., 2005, p. 79). The findings show that this fragmentation is evident across all seven system functions and value chain stages. Wool supply is distributed among many farms, processing is carried out by small-sized and often isolated actors, and linkages between stages remain weak and largely dependent on informal, personal networks. Initiatives act independently and have minimal effect on changing the system. As explained in the value chain literature, this systemic fragmentation increases transaction costs and limits economies of scale, while also constraining collective learning and knowledge diffusion (Kaplinsky & Morris, 2001). Although decentralised structures can, in some contexts, support niche experimentation and innovation (Geels, 2002), the Slovak case demonstrates that fragmentation leads towards inefficiencies and underutilisation of resources. The results also correspond with discussions from the EU CAP Network focus group on wool, which identifies fragmentation as one of the key structural barriers to wool valorisation in Europe.

As fragmentation spans all stages and actors across the value chain, there is no simple solution. First, literature suggests that horizontal collaboration through producer organisations and agricultural cooperatives enables actors to jointly address structural challenges by producing “club goods” (Nilsson, 2016). These members may share services such as infrastructure and information, thereby collectively overcoming market failures associated with dispersed production while steering clear of free riding by non-members. Second, vertical coordination through more stable relationships between producers and between processors can reduce uncertainty and improve the flow of material and information across the value chain (Gereffi et al., 2005). Third, network-based forms of organisation can improve communication and trust, especially when creating industrial symbiosis between processors, where waste or by-products from one process are used as inputs in another for mutual benefit (Chertow, 2000). Related to this, shared infrastructure within clusters can lower individual costs and increase overall efficiency. These approaches primarily address structural fragmentation, but their effectiveness ultimately depends on the presence of coordination mechanisms that align actors across.

6.1.2 The vicious cycle

The challenges observed in the Slovak wool sector can be further understood as a self-reinforcing vicious cycle that locks the system into a low-value equilibrium. This dynamic has been identified in the literature, with the main reason being weak market organisation (Klepp & Tobiasson, 2022). In the Slovak case, this cycle begins at the production level, where farmers widely perceive wool as a waste or low-value by-product. This perception directly influences breed selection, with farmers prioritising meat or dairy characteristics over wool quality and even opting for short-wool breeds. Farmers are disincentivised from committing to quality improvements such as careful shearing, sorting, or storing of fleece; consequently, the quality and consistency of raw fleece supply remain low, creating further downstream challenges for processors, who struggle to access suitable material for higher-value applications. The buyers are then unwilling to pay higher prices or enter into long-term agreements with producers. At the end of the day, neither producers nor processors are motivated to improve quality or grow operations. Wool thus remains embedded in a system that continuously reproduces its low-value status. Importantly, no single actor within the system can break this cycle independently because improvements at one stage are constrained by shortcomings in the other stages.

Given the observed tension over the regulatory classification of wool as an animal by-product, it is worth asking whether reclassification could contribute to its higher perceived value. As outlined in Section 2.4.1, the regulation itself does not prohibit wool valorisation, but regulates the conditions under which raw wool may be managed before the use (Regulation (EC) No 1069/2009). Wool can therefore enter textile, technical, agricultural or any other product pathways, provided relevant sanitary and traceability requirements are met. The findings suggest that the main problem is therefore how regulatory requirements are experienced in a weakly organised system consisting of small-scale actors, because these requirements raise complexity and transaction costs, which then discourage certain actions. Respondents were not always clear on how these rules apply in practice, although one referred to documentation and quarantine requirements when transporting raw, unprocessed wool across borders (S6). Beyond these practical burdens, it seems that such classification most importantly affects wool's perception as a problematic, low-value material, making investment and valorisation less attractive. Reclassification could therefore primarily improve the perceived legitimacy and value of wool. Overall, the evidence suggests that the current regulatory framework fulfils the purpose of environmental and human safety, and is not the determining factor behind wool underutilisation in Slovakia. Its role is secondary to deeper systemic barriers. Thus, it is fair to conclude that reclassification alone would not transform the Slovak wool sector but could help trigger action.

Breaking this cycle, therefore, requires a change in the system's underlying incentive structure. As one interviewee noted, farmers would take any extra steps to preserve wool quality if the price justified the effort (S9). The issue is therefore not simply unwillingness, but the absence of price signals that make quality improvements worthwhile. These signals are shaped by existing power asymmetry described in Section 2.5.1 in the value chain literature (Kaplinsky & Morris, 2001). Farmers currently have limited bargaining power and largely act as price-takers, while buyers are better positioned to set prices and quality expectations. A classification system, established through price negotiations among farmers, traders, and processors, could help make quality differences visible and link them to fairer prices, moving the system towards a Pareto-optimal arrangement without making any actor worse off (Ng, 1979). However, as with fragmentation, such coordination is unlikely to emerge without intermediary actors or targeted public support.

6.1.3 Absence of coordination

A central weakness of the Slovak wool system, which is highly interlinked with fragmentation and the vicious cycle, is the absence of a recognised coordinating body capable of guiding sector development. This finding is the most consistent with the literature, which identifies coordination as a central

leverage point for system transformation (Kaplinsky & Morris, 2001; Špinková, 2025; Van Acker, 2024). At present, no actor in Slovakia currently assumes ownership or responsibility for the sector, leaving coordination functions unfulfilled. In the absence of a legitimate coordination body or framework, fragmented actors may remain individually adaptive but collectively ineffective. How the system governance can potentially be organised is further reflected on in the next Section 6.2.1.

In addition to national coordination, regional cooperation across countries could create economies of scale, enable shared processing infrastructure, and strengthen cross-border market integration. Examples such as the Nordic Wool Initiative or Alpine wool cooperation project illustrate how regional approaches can support wool systems beyond national boundaries.

6.2 Leverage points

The findings show that, other than the barriers, the Slovak wool system has several strengths that provide an underpinning for future development. First, entrepreneurial activity appears to be the strongest among all the system functions. A key asset is the high level of motivation among actors, many of whom are actively seeking ways to make their wool-based businesses viable and reposition wool within contemporary markets. In addition, many of whom are actively involved in organisations or initiatives that are trying to build the system bottom-up, showing a strong sense of entrepreneurial persistence. Another strength appears to lie in the growing consumer awareness of sustainable and natural materials, which is fostering new communities of wool enthusiasts and opening opportunities for niche demand. Slovakia also benefits from a rich cultural heritage of shepherding and traditional wool-based clothing. This heritage yields potential for marketing wool through modern design in ways that consumers may value. Finally, the relatively small national scale of Slovakia and shorter distances compared to other European countries represent an advantage, as less complex logistics may be sufficient to facilitate coordination.

6.2.1 System governance leverage

A comparison from Section 2.5.2 of models from Iceland, the UK, and Norway points to a common feature despite their structural differences. Wool systems count on a clearly defined responsible body to organise wool flows. In Iceland, this role is played by Ístex, the dominant wool processor. British Wool is a central institutional body in the UK, and in Norway, wool collection is organised through Norilia and Fatland Ull within a state-supported grading and payment system.

In Slovakia, interviewees most frequently identified association ZCHOK as the closest existing candidate for such a role, given its representation of sheep farmers. However, wool does not officially fall under its mandate and is not prioritised. From their side, it is treated more as an additional activity they take on only when resources allow. In principle, the Slovak wool system could self-organise without a central coordinating actor. However, this would require a high level of voluntary collaboration among already resource-constrained actors. Such spontaneous coordination appears unlikely in practice, as many actors are already operating beyond the limits of their resource capacities. A coordinating body could therefore play an important part in strengthening all the system functions, more specifically, aggregating wool nationally, setting strategic direction and lobbying, mediating prices, developing and sharing knowledge through training, offering necessary guidance, and promoting wool externally.

Who may become the coordinating body?

Several pathways for establishing a coordinating actor can be considered. One option is to strengthen an existing organisation, such as ZCHOK or Naša Vlna, by assigning a mandate and providing targeted resources. However, this would call for careful design to ensure neutrality and avoid bias toward either supply or demand-side interests. The structure would need to be transparent and clearly assigned, with the ministry's support, to gain authority and trust between actors.

A pathway of Iceland appears less likely, as Slovakia currently lacks a large-scale processor capable of absorbing the full wool supply. However, an adapted version of this model could be considered. One existing market actor currently innovating in processing larger volumes of wool could take on this role in the future and steadily expand its business model. Based on the interviews, Wool Style has a high potential to fulfil this role, particularly if supported by other actors in the system to gain legitimisation.

A third option would be to create a new, neutral coordinating body. This model could take different institutional forms, state-led or cooperative. A state-led model could provide strong authority and access to funding, but it may also risk bureaucratic shortcomings and high political dependency. This is very unlikely because the guidance of search function has been assessed as the weakest of all. Alternatively, a cooperative model with public support could allow the sector itself to own and run the coordinating body, while the state helps make it financially viable if needed. The cooperative would generate revenue by collecting and selling wool. Actors from across the sector, contributing through a small annual fee, would become members. For this model to be sustainable, government support in the early stages of implementation and during periods of low prices would be necessary to encourage actors to sign up and stabilise income. This structure would combine sector ownership with financial independence in the long run. In both cases, organisations such as ZCHOK, Naša Vlna, and others would still play an important role by representing the needs of different actor groups and assisting in price and quality negotiations.

Reflecting on the barrier identified in Section 2.4.1 on the limited scope for direct governmental support under EU state aid rules, targeted policy support would be feasible if kept transparent and justified. In this case, policy objectives such as environmental protection, circular economy, bioeconomy, and rural development are all consistent with the challenges facing the wool sector. Overall, regardless of the specific institutional configuration, the key requirements are the establishment of a clearly mandated responsibility and the provision of sufficient resources to coordinate across the system.

6.2.2 Dynamic leverage: Interpreting findings through TIS motors

Building on the concept of motors of change outlined in Section 3.3, the Slovak wool system does not currently exhibit a positive self-reinforcing dynamic within functions. The question, therefore, is where such a dynamic could realistically begin. For a motor of change to develop, one or several system functions must first strengthen enough to trigger positive feedback loops across the wider system. In this case, the data show that a policy-led pathway, Motor A, starting from guidance of search, may be difficult to realise.

Therefore, the momentum is likely to emerge from Motor B, entrepreneurial activities, because this function was assessed as one of the strongest in the system, with motivated actors already experimenting with wool-based products, building communities, and keeping the system active despite the challenges. According to the theory, if these actors leverage this momentum to strengthen collaboration and build stronger networks, they could increase their collective influence and more effectively engage in lobbying for either a coordinating body or resource mobilisation, such as targeted policy support. Nevertheless, once the system begins to develop, value chain strengthening should proceed gradually and iteratively in a spiral-like motion without forgetting any actor or stage.

6.2.3 Structural leverage points: Aggregation and classification

A key structural leverage point in the Slovak wool system is to improve coordination through aggregation mechanisms, particularly by establishing collection hubs. Given Slovakia's relatively small geographic area of 49,000 km², logistical distances do not pose a major barrier, and none of the respondents identified them as such. This suggests that either a single centralised centre or a small

number of regional hubs could be sufficient to organise wool flows effectively. It is understood that such facilities would still require human labour and well-trained personnel to function. Once established, they could aggregate and classify dispersed supply to create more predictable volumes for the buyers and improve wool quality through proper handling and storage, thereby to support downstream processing and market development.

While the absence of domestic scouring capacity was identified as a primary bottleneck, existing processing capacities in neighbouring countries, such as Poland or the Czech Republic, may provide viable alternatives in the short to medium term. Once wool is aggregated into sufficiently large volumes, these facilities can be used without difficulty, as minimum-volume thresholds cease to be a constraint. Rather than prioritising immediate investment in domestic scouring infrastructure, resources may be better spent strengthening collective organisation and aggregation. This seems like a more critical first step, and over time, this system may create favourable conditions for further scouring capacity to emerge spontaneously.

Is the classification system essential?

Botha & Hunter (2010) claim that because wool characteristics can vary considerably even within a single fleece, quality assessment is fundamental for efficient marketing and processing. While this is important, the interview data did not identify the absence of a classification system as a primary constraint for Slovakia. The lack of an official classification system is not a barrier, as most market actors assess wool quality directly with their suppliers in person. This is feasible when working with smaller batches and within local networks, in which trust can be established over time, but the relevance of classification increases as the system scales. For larger processors or international buyers, classification provides a shared language for quality (Axfoundation & Norion Consult, 2025). In transactions wherein direct interaction is not possible, it would be essential to increase transparency and enable fair price formation. Importantly, it can also help ensure that higher-quality wool is directed towards appropriate uses and is not downgraded.

At the same time, this study cannot determine the most appropriate design for a classification system in Slovakia. It remains uncertain whether present models from other countries, for example, the Swedish classification system, could be applied directly to the Slovak context. A shared language across Europe would benefit the wider wool market, but it also risks becoming too complex for some of the less developed countries. Interview data suggest that a simpler system would be more effective in Slovakia, given the country's smaller scale and fewer wool applications. Rather than aiming for highly precise classification, the objective should be to classify wool sufficiently enough to enable transactions. This implies a system that is simple to apply, reliable for buyers, flexible over different end uses, and capable of gradual development over time. While Norway, Sweden and the UK use relatively detailed and complex classification systems, Iceland provides an example of a simpler system tailored to national market needs. The Icelandic model could serve as a useful starting point for Slovakia to draw inspiration from when exploring its own approach.

6.2.4 Market leverage points: Diversified uses and symbiosis

Different market actors face distinct constraints depending on their position within the Slovak wool value chain. Textile actors typically require smaller batches of higher-quality wool, as well as access to suitable washing and spinning infrastructure. In contrast, construction actors need larger volumes of wool from a stable, reliable supply. They have a higher tolerance for coarser material alongside greater flexibility in processing. Agricultural uses, although currently niche, could provide a scalable demand for the lowest-quality wool, keeping what might otherwise be “waste material” from other applications within a circular model.

The differing requirements from actors suggest that they are not necessarily competing, but may instead have complementary needs. This creates potential for market symbiosis through a cascading-use approach, in which wool of different qualities is directed to the most suitable applications, thereby maximising its value across multiple pathways. For the Slovak wool system, such diversification may ultimately prove a more resilient and feasible option than relying on a single dominant market or one large processor.

Realising this potential, however, depends on the infrastructure to support it. Aggregation and classification through collection systems could play a key role in directing wool to where it is best suited, while greater overall availability would lower barriers for new market entrants. It would also open the door to innovation in areas such as bedding, carpets, packaging, filtration materials, and even lanolin extraction for pharmaceutical or cosmetic use, which only becomes economically viable at larger processing volumes.

6.3 Contribution of the study

This study contributes to TIS literature by showing that the framework can be applied not only to the emergence of new technologies, but also to the failure of existing biological resources to become economically organised. In the Slovak wool case, the challenge is not the diffusion of a specific technology, but the weak performance of system functions around an already available material that supports innovation. The study, therefore, extends TIS to a context where “innovation” primarily refers to value chain formation and system development.

The study is particularly relevant to bioeconomy research, in which bioeconomy literature mainly emphasises cascading use and the versatility of biomass application across sectors. The Slovak case shows that for these concepts to be implemented in practice, it is equally important to examine not only “what materials can do”, but also how the system must be organised around biological resources to preserve their highest value during utilisation by shifting the attention to a systematic analysis of barriers and enablers of system organisation.

In this way, the study likewise contributes empirical value through a detailed mapping of the Slovak wool value chain and its actors, addressing the bottlenecks in a structured manner. This mapping brings greater visibility to the wool system and may benefit Slovak policymakers and market actors, while also serving, not least, as a contribution to awareness-raising. At a higher level, the findings may inform initiatives such as the EU CAP Network focus group on wool, which needs to account for national differences when designing policy steps. Although many barriers overlap alongside those observed generally across the European wool sector, the underlying mechanisms and system structures through which each state must address them differ.

6.4 Limitations and future research

This study sought to explore the Slovak wool value chain using a qualitative, interview-based approach. While this approach made it possible to collect in-depth insights from different actor groups, several methodological and empirical limitations need to be acknowledged. At the same time, these limitations point directly to relevant avenues for future research.

Although 12 interviews were conducted in total, covering multiple stakeholder groups, the sample size of representatives from each group remains small relative to the national scope of the study. The researcher is aware that, specifically, in the farmer actor group, only three interviews constitute a small representative sample, given the 9,000 farms spread across the country. Therefore, the study may not have adequately captured the diversity in how wool is handled or perceived, given that there are many different farming and wool-handling practices.

Another important limitation is the lack of quantitative sector data. This study cannot provide precise figures on wool volumes, material flows, or disposal pathways within the Slovak wool value chain. The estimates used are based on interviewee accounts and desk research rather than statistical national data. More reliable figures would allow the scale of inefficiencies to be identified more accurately and targeted more effectively. This and the previous gap could be addressed by carrying out additional anonymous farmer surveys with a larger sample size to collect systematic data on disposal streams, types of fleece, and volumes produced.

Furthermore, the study delivers limited insight into consumer demand. Consumers were not directly included in the research, which limits understanding of consumer awareness and willingness to pay for wool-based products. This is important because demand holds a decisive role in market formation. Additional research should therefore examine consumer demand more directly to inform market positioning and product strategies. Without these understandings, it remains unclear whether future market development should primarily target domestic consumers or instead focus on value opportunities in international markets. Whether or not this will be the case, future studies may focus on mapping wool-related infrastructure across the wider region to help identify cross-border bottlenecks and opportunities for regional partnerships. Attention should be given to which neighbouring countries or localities could become strategic partners and what forms of cooperation would be most effective, whether shared processing facilities, coordinated logistics, joint classification systems, or regional branding.

In this context, developments within the EU CAP focus group on wool offer an important area to keep an eye on. Ongoing efforts to create a strategy to introduce a common classification system and to map the EU-wide wool value chain may provide new data and potentially create a top-down push for change. Future research could examine whether these initiatives result in tangible improvements at the national or regional level.

7 Conclusion and recommendations

This thesis set out to identify the system-wide conditions shaping the valorisation of sheep wool in Slovakia and to assess how the current wool system could be strengthened to form a more functional value chain. Building on the understanding that any wool of varying qualities can be used when matched to appropriate end uses (Rajabinejad et al., 2019), the thesis examined why this potential is not currently realised in the Slovak context.

RQ1: How is the Slovak sheep wool value chain currently organised?

While the actors, material, and the applications exist, wool falls through the gaps between them; the value chain is not absent, but structurally incomplete. The value chain contains sheep farmers, traders, residual textile processing capacity, small textile brands, construction and emerging agricultural applications, knowledge support actors, sectoral associations, and active civic initiatives, all of whom contribute to value creation. The central finding is that a high variety of actors are present, but no actor is currently large enough or sufficiently positioned to organise the system as a whole.

What these actors lack is the connective tissue between them. The weakest point in the value chain is currently the “missing middle” between farmers and processing: the absence of collection centre and a medium-scale scouring that could connect farm-level wool with domestic uses. As a result, wool is shorn off the sheep and left at the farm, waiting for someone to pick it up, even for free, because farmers lack direct channels for selling it. Wool is often either exported to neighbouring countries or wasted. The main value loss, therefore, occurs before wool can properly enter a market. In the few cases where wool does enter the market, existing links currently rely on informal personal networks. Market actors struggle to access consistent local wool and commonly rely on imported, already scoured wool instead. Existing industrial facilities can process wool only after scouring and are too large or inaccessible for textile processors, while the wool mini mill has created an important niche solution, though its capacity remains too limited to serve the wider sector.

However, closing this gap is not simply a matter of building scouring capacity. Scouring facilities, whether domestic or foreign, require a minimum volume of wool to operate viably; without first aggregating dispersed farm-level wool into consistent, sufficiently large batches, any new or existing scouring capacity would remain just as underused or inaccessible as current facilities already are. Aggregation is therefore the precondition for the missing middle to be filled at all, whether through new domestic infrastructure or by making existing foreign facilities genuinely usable. Prioritising aggregation would have a greater systemic effect, as it would unlock both routes simultaneously, whereas focusing on scouring infrastructure alone would only address one possible solution without resolving the underlying volume constraint.

RQ2: How do key system functions of the Slovak wool sector perform in enabling value chain development?

The Slovak wool system contains promising elements, but not yet the functional strength needed to activate a positive self-reinforcing dynamic. As summarised in Table 7, none of the seven system functions performs strongly. Entrepreneurial activity (F1) is the strongest function, with several motivated actors building the system bottom-up and experimenting with wool-based products across textiles, insulation, pellets, local design, and other particular applications despite existing constraints. This is important because it shows that Slovak wool can be used commercially and that value creation is possible. However, these activities stay relatively isolated. They have not yet generated the wider coordination needed to strengthen the system.

Other functions that are emerging, even though assessed as currently weak, are market formation (F5) and legitimisation (F7). Market formation is directly connected to F1 because entrepreneurs create the offer, thereby creating space for growing demand. Wool is slowly gaining legitimacy through consumer

interest in natural materials for housing and clothing, as well as through active civic initiatives aimed at creating awareness. Even though this process is slow and targets a specific customer group, it still grows over time.

The weakest function of the system is the guidance of search (F4). No single actor holds recognised responsibility for developing the Slovak wool sector. Without a coordinating body to set direction, there is no overarching strategy, and without a strategy, the sector drifts. Knowledge development (F2) and knowledge diffusion (F3) are also weak. There are weak academic links to the wool sector, despite identifying one successful case of collaborative effort in this study. The question is not only how to create new knowledge but also by whom and how it will be communicated further, directly being linked to the missing responsible body in F4.

Lastly, resource mobilisation (F6) performance is uneven across sectors. Construction and agricultural actors are better positioned to mobilise larger volumes because they work with lower-grade wool and organise processing within their own production systems. Textile actors face a more difficult situation because wool must pass through several specialised stages, during which they are dependent on partners. The current brands work with small to medium quantities. For them, the absence of accessible scouring and processing capacity is a major constraint.

SYSTEM FUNCTION	ASSESSMENT
F1 Entrepreneurial activities	Weak / Moderate (emerging)
F2 Knowledge development	Weak
F3 Knowledge diffusion	Weak
F4 Guidance of search	Very weak
F5 Market formation	Weak (emerging)
F6 Resource mobilisation	Weak / Moderate
F7 Legitimation	Weak (emerging)

Table 7. Assessment of system functions.

Overall, the function assessment indicates that any positive system dynamic would most presumably originate from entrepreneurial activity (F1), as this is currently the strongest function. Entrepreneurs are already demonstrating that Slovak wool can be used commercially, which thereby supports early market formation (F5) and slowly strengthens legitimation (F7). However, this momentum remains too weak to become self-reinforcing because other functions are underdeveloped. Weak guidance of search (F4), limited knowledge diffusion (F3), and uneven resource mobilisation (F6) prevent entrepreneurial activity from spreading across the system. Strengthening the system would therefore require building on entrepreneurial activity while increasing the collective influence of market actors and farmers to advocate for resources or a coordinating body. At the same time, supporting functions would need to improve so that progress in one part of the value chain does not create new bottlenecks elsewhere.

RQ3: Which barriers and enablers explain the current performance of system functions in the Slovak wool sector?

The findings identify three main hindering patterns that point to a wider systemic condition constraining the performance of the Slovak wool value chain. First, the sector is highly fragmented across all stages of the value chain, with dispersed supply, isolated small-scale actors, and linkages that remain weak and largely dependent on informal, personal networks. Second, it is trapped in a "vicious" cycle of low demand, low prices, and limited incentives for quality improvement or investment, in which farmers' perception of wool as a low-value by-product discourages breed selection and quality practices that would otherwise attract better prices. Third, the absence of a coordinating body or institutional framework weakens actors' alignment and their collective ability to maximise total value, leaving no actor currently positioned to guide the sector as a whole. These three patterns are closely interlinked, each reinforcing the others, and together explain why the system's seven functions perform weakly overall.

These barriers are partly offset by several enablers. Entrepreneurial activity stands out as the strongest system function, driven by highly motivated actors who are actively working to make wool-based businesses viable and are often involved in bottom-up initiatives to rebuild the system. Growing consumer awareness of sustainable and natural materials is fostering new communities of wool enthusiasts and opening niche demand opportunities. Slovakia's rich cultural heritage of shepherding and traditional wool-based clothing further offers potential for marketing wool through modern design in ways that resonate with consumers. Finally, Slovakia's relatively small national scale and shorter distances compared to other European countries represent a logistical advantage, potentially making a simpler, less complex system sufficient to organise the value chain.

As actors working in different applications are not in direct competition for the same wool quality, there is a strong potential for industrial symbiosis, where construction actors may utilise larger volumes of coarser wool, while textile actors process the smaller available quantities of better-quality, better-prepared fibre. Agricultural applications can use the residual wool unsuitable for others. This means Slovak wool does not need one single market; it needs a system capable of separating different wool qualities and directing them to correct uses. A well-established collection and classification system can help with this allocation.

Taken together, the three research questions answer the overall aim of the thesis. A coordinated sheep wool value chain has not emerged in Slovakia because the value chain is currently fragmented, the system functions are weak, and the structural conditions needed to connect wool with suitable uses are underdeveloped. In principle, the system could self-organise without a coordinating body, but considering it would require a high level of voluntary cooperation between already resource-constrained actors, such coordination might take years and appears unlikely in practice.

7.1 Recommendations and practical implications

Based on the findings of this thesis, I recommend that the Ministry of Agriculture and Rural Development support the establishment of a new, neutral coordinating body: the Slovak Wool Board. Although several possible scenarios were considered regarding the form such a lead actor could take, I argue that an independent, nationally recognised organisation would provide the strongest foundation for long-term system development. The board would be responsible for sector coordination and representation. It does not need to be large, but its creation would itself send an important signal of institutional commitment behind it. Public support should be understood as an initial enabling mechanism rather than a permanent funding model. From the beginning, the board's business model should be designed so that it can become financially independent within a relatively short period, for example, through membership fees and commissions on wool sales. The Slovak Wool Board should, in this way, have an explicit public recognition, transparent responsibilities, and accountability to farmers, market actors, and public authorities.

Its starting objectives should be practical: to map available wool volumes across farms, identify demand among market actors, develop basic classification rules, negotiate price categories, and run a pilot project to test the full chain. The pilot could determine whether this pathway is sustainable in the long run and whether the investments are worth it. If the pilot project fails, the board could pursue other options, such as cross-regional collaboration with neighbouring countries.

Public support should prioritise the missing middle of the value chain, but not through domestic scouring infrastructure. As noted earlier, scouring facilities require minimum viable volumes to operate, and Slovakia's dispersed, unaggregated wool cannot yet meet these thresholds; building domestic scouring capacity before demand is proven would risk creating expensive, underused infrastructure. Aggregated Slovak wool can instead make use of existing scouring facilities abroad under contractual agreement in the short to medium term. What the system lacks and urgently needs, however, is collection capacity: a function that consolidates dispersed farm-level wool into volumes large enough to be usable, whether by foreign scouring facilities today or by domestic ones in the future. If Wool Style or another market actor is willing to develop this collection function, public support should reduce the risk for the first mover and help establish it, provided that the supported infrastructure serves wider sectoral needs. Such an actor could then operate the practical chain for further sale to different end-use markets, particularly construction, agriculture, and textiles. The Slovak Wool Board would retain responsibility for neutral coordination, representation, classification rules, and price negotiation, while the other actor could contribute operational capacity.

Within this system, Slovakia should start with a simple use-based classification scheme, as a complex grading system would be unrealistic at this stage and could discourage participation. Wool should be sorted into four main practical categories based on final use: textile-quality wool, construction or insulation wool, agricultural-use wool, and contaminated or unusable wool. To establish such a classification, market actors should define their minimum requirements for fibre quality and volumes. Farmers should not be asked to improve wool quality without being paid for it. Therefore, any quality handbook or shearing training should be linked to a price structure: cleaner, better-stored, and better-separated wool should receive a higher price. Otherwise, quality improvement becomes an unpaid task pushed onto farmers.

Under Regulation (EC) No 1069/2009, lower-quality wool should be given a less burdensome pathway for direct on-farm use where health and environmental risks are low. Farmers should be permitted, under defined conditions, to apply their own unprocessed low-grade wool into the soil as a slow-release nutrient source without being subject to requirements designed for higher-risk animal by-products. A simplified on-farm pathway would, in doing so, reduce transport and treatment costs for some low-value wool while keeping it within rural circular systems.

Finally, the most urgent research needs are tied to implementation and span multiple fields. Slovakia needs more precise data on wool volumes and quality to determine national supply, specific buyer requirements, environmental impacts of wool on-farm use, and the financial model of a coordinating body, including logistics costs and expected profits, to calculate how quickly the Slovak Wool Board can become financially independent. Universities and testing institutions should be involved in these discussions. Ultimately, Slovak wool does not need more proof of its potential. It needs a system capable of turning that potential into organised value.

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Appendix A

Consent to Participate in Research

Researcher

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Purpose of the Research

This research is part of a Master's thesis at Lund University and focuses on the utilisation of sheep wool and the functioning of its value chain in Slovakia. The research aims to understand better how the sheep wool sector is organised, the main barriers to its utilisation, and the opportunities for its further development.

What Participation Involves

You have been invited to participate based on your professional experience or involvement in the sheep wool sector (for example, as a farmer, entrepreneur, processor, or representative of an organisation).

Participation involves a semi-structured interview lasting approximately 30–45 minutes.

The interview will focus on your experiences, opinions, and observations regarding the sheep wool sector, its challenges, and potential opportunities for further development.

The interview will be audio recorded only for accurate transcription and subsequent analysis as part of the Master's thesis. All recordings will be deleted after the completion of the thesis.

Participation in the interview is entirely voluntary. You may decline to answer any question and may withdraw from the interview at any time without providing a reason and without any consequences.

Data Processing and Confidentiality

No sensitive personal data will be collected during the research. Your name and identity will be anonymised in the thesis. However, the thesis may indicate the type of actor you represent (for example, farmer, company, processor, or organisation).

If a direct quote from the interview is used, additional consent will be requested from the participant.

The collected data will be used exclusively for academic purposes and stored securely in accordance with Lund University research standards.

Use of Results

The results of the research will be used for the Master's thesis. They may contribute to a better understanding of the sheep wool sector's functioning and development opportunities.

Please confirm the following:

- ☐ I have read the information about the research and understand its purpose.
- ☐ I understand that my participation is voluntary and that I may withdraw at any time without giving a reason.
- ☐ I understand that my name and identity will be anonymised, although the type of actor I represent may be indicated in the thesis.
- ☐ I agree to participate in this research.
- ☐ I agree to the audio recording of the interview for transcription and analysis.

Name of the researcher: Michaela Hladká

Name of the participant:

Date:

Appendix B

■	Core Questions
■	Intermediary Actors
■	Primary Producers
■	Market Actors

1. Introduction

- Could you briefly describe your role and involvement with sheep wool in Slovakia?
- How long have you been involved in activities related to wool?

2. Understanding the current wool system

- From your perspective, how does wool typically move through the system in Slovakia? What are the volumes produced and wasted/utilised? What actors are involved?
- What happens to the wool produced on your farm after shearing? Do you currently receive any income from wool?
 - *If yes:* If the wool travels through the system, can you explain what the steps and actors are involved? Are there specific practices required on farms to prepare wool for sale or processing?
 - *If no:* If you do not sell wool, what are the reasons for it? How do you handle it instead?
- How does wool travel to you through the system until it reaches your company? And what actors are involved?
- Are there challenges related to collecting, transporting, or coordinating wool between farmers and processors?
- Are there activities related to Slovak wool that take place outside Slovakia that you know of? If yes, why?
- In your opinion, how would a well-functioning wool value chain look? What elements (actors, processes or infrastructure) are currently missing in Slovakia?

3. Market situation

- How are wool prices determined? Are they stable or do they change? Are they fair?
- How would you describe the balance between demand and supply?
- What challenges do farmers face when trying to sell wool?
- How easy or difficult is it to source Slovak wool?
- Do you think there are enough businesses or initiatives in Slovakia working with raw wool or developing new wool-based products?
- Is wool able to compete with synthetic and cheaper products?

4. Perception and Legitimacy

- How is wool perceived today in Slovakia?
 - a) Do people generally see wool as a valuable resource or more as a waste product?
 - b) Are there initiatives promoting wool or raising awareness about its potential uses?

5. Processing Capacity and Resources

- Does Slovakia currently have the resources needed to utilise wool effectively?
 - c) Are there enough processing facilities (washing, sorting, spinning)?
 - d) Are there sufficient investments or financial support?
 - e) Are there enough skilled people in the sector?
 - f) Are there challenges related to wool quality or quantity?

6. Knowledge and Collaboration

- How do actors in the wool sector exchange information and cooperate?
 - a) Are there networks or organisations connecting actors?
 - b) Are farmers or businesses supported through training or workshops?

7. Policy and Future Direction

- What role does government or policy play in shaping the development of the wool sector?
 - a) Do you think the sector has a clear vision or strategy for the future of wool in Slovakia?
 - b) Are there policies or regulations that support or hinder wool utilisation?
 - c) Are there standards or certification requirements related to wool quality that make it difficult to use wool in certain products?
 - d) How are EU policies influencing the development of the sector?

8. Other Barriers and Opportunities

- What are the biggest obstacles to developing a functioning wool value chain in Slovakia?
- What pathways do you see for better utilisation of wool? What policy or institutional, economic, or structural changes would help develop the sector?

9. Closing Remarks

- Is there anything important to understand about the wool sector that we have not discussed?
- Would you recommend speaking to any other actors who might provide valuable insights?