ITALY GREENTEX HUB

Boosting Circularity in Textile Sector

Services and Opportunities from Italian Textile Ecosystems

Co-funded by the European Union

REGIO GREEN TEX

NEXT TECHNOLOGY TECNOTESSILE SOCIETA' NAZIONALE DI RICERCA R. L.

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Città Studi BIELLA

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Introduction

The manufacturing sector is at a turning point, and the textile industry must undergo a deep transformation as well.

Environmental challenges, forthcoming EU regulations, and shifting market expectations are driving the sector toward new business models in which circularity is no longer an option but both an economic and environmental necessity. For companies, institutions, and stakeholders, this transition represents both the challenge of adapting to new rules and operational complexities, and the opportunity to innovate, create value, and contribute to a more sustainable future.

Italy occupies a distinctive position in this transition.

For more than a century, the textile districts of Prato and Biella have been pioneers in the collection, sorting, and regeneration of textile waste (mainly wool). What began as a pragmatic response to material scarcity has gradually evolved into a sophisticated ecosystem of recycling practices that anticipated the principles of the "Circular Economy."

Their heritage of artisanal know-how, industrial collaboration, and technical creativity, now combined with technological advances, industrial symbiosis, and collaborative innovation, positions these districts as a reference point for Europe and beyond.

Despite their long-standing achievements, the systems and practices of Prato and Biella have rarely been mapped in a structured, systematic way. Much of the districts' knowledge has remained tacit, passed along through practice rather than documented for wider replication. This report, developed within the framework of the RegioGreenTex project and the ItalyGreenTex Hub, provides a preliminary overview that may help address that gap.

By reconstructing processes, mapping value chains, and gathering insights and perspectives from key stakeholders, the report preserves a legacy of technical expertise while making it accessible as a basis for future development.

At the same time, this report looks forward. It identifies current barriers and emerging opportunities, examines promising recycling technologies, and connects local experience with the broader European regulatory and innovation landscape. The goal is not to prescribe a single path, but to provide practical orientation and evidence-based options that stakeholders can use to plan their own transitions.

The strength of this work lies in its combination of research and lived experience. Quantitative analysis, technology scouting, and field data are complemented by the voices of companies, associations, and operators who work daily with textile recycling. Their testimony reminds us that circularity is a practical endeavour made up of contested choices, technical constraints, and collaborative problem-solving involving the whole ecosystem.

This document is therefore intended as a practical tool. For companies, it offers insights and methodologies to navigate change and strengthen competitiveness. For associations and consortia, it provides a framework to coordinate shared action. For policymakers and institutions, it highlights the on-the-ground realities of the sector and the necessary conditions to scale circular practices effectively.

This report reflects an industrial journey and suggests possible next steps in textile circularity. It seeks to contribute to the shared goal of preserving skills, improving practices, and developing systems for a more circular and resilient textile sector, without presumption, but with the awareness that documenting practices refined over decades can provide both perspective and guidance.

Acknowledgements

The authors would like to express their sincere gratitude to the companies and stakeholders who contributed their time and insights during the interviews. Over the past year, their support has been invaluable in addressing topics that are deeply rooted in the Prato and Biella districts. These actors often find themselves reiterating the same challenges, while only gradually seeing change unfold to their benefit. Their willingness to share experiences has been essential to this work.

We also wish to thank the local industrial associations, whose collaboration was crucial in identifying the most representative companies and in providing contextual information on the issues addressed in the report. Their contribution highlighted the importance of standardizing the field of mechanical wool recycling, so that data, metrics, and evidence-based information can be effectively brought to the European level.

Finally, we are deeply grateful to all the partners of the RegioGreenTex project, from which this report originates. Throughout the project, their continuous input and constructive discussions have provided valuable perspectives and insights, many of which have been instrumental for the preparation of this study.

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PRATO-BIELLA

1. Objectives of the Research

With increasing regulatory pressure, environmental urgency and industrial complexity, the **Italian textile industry** *is called to lead by example. For over a century, districts like Prato and Biella have pioneered the collection, sorting and regeneration of textile waste - long before the term "circular economy" existed. This report offers a data-driven exploration of how this historical know-how, rooted particularly in the recycling of end-of-life fashion products and textile scraps, can now be systematized to meet the urgent need for textile circularity. Tradition, innovation, traceability and design/produce-for-recycling converge to position Italy as a reference model in Europe's transition.*

This report is developed within the framework of the **RegioGreenTex** project ("RegioGreenTex – Regions for Green textiles. Strengthening textile circularity in Europe's regions" N. 101083731). The project aims to establish **a new model for textile recycling** by mapping existing challenges and providing solutions to enhance circularity across the European Union's textile ecosystem (*https://www.regiogreentex.eu/dashboards/home*). Led by Euratex and involving 43 partners from 11 regions, including 24 SMEs, the project addresses key bottlenecks in the value chains of the recycled textiles and sized market opportunities through innovative practices in sorting, fiber-to-fiber recycling, contaminant removal and processing recycled fibers into new materials. RegioGreenTex will foster the development of 5 regional recycling hubs (ReHubs) in key European textile regions and contribute to the European Green Deal objectives, aiming to reduce carbon emissions, water consumption and energy usage. During the research activities and field observations, the partnership identified several structural and operational challenges that currently hinder the effective recycling of textile materials. Therefore, it is essential to complement the core objectives of the project with a series of short- and long-term improvement proposals, which will be presented within the current report. This approach aims to ensure continuity in the work and to foster concrete and lasting results in the field of textile recycling.

What purpose does this report serve within the RegioGreenTex project - and what value does it bring to the broader European textile ecosystem?

A Collaborative mapping effort for Circular progress

Two key guiding principles of this report are "mapping" and "partnership", in line with the approach of the RegiogreenTex project. The project partners have joined forces to collaboratively **share existing knowledge about textile waste management** and ongoing efforts to establish recycling hubs. The goal is to horizontally disseminate best practices across regions and industries while building on current advancements rather than reinventing the wheel. This approach ensures that the knowledge gained from previous experiences in Europe and beyond can be leveraged to achieve faster, more efficient innovation.

The Italian success story of Circularity

In Italy, the study of best practices in textile recycling naturally centers on **wool recycling**, as exemplified by the extensive expertise of the historic and globally renowned districts of Prato and Biella.
The **Prato** and **Biella** textile districts, long recognized as centers of excellence for textile recycling, form the core of this research.

Prato district, which has been recycling wool for over a century. This long-standing practice began during a period of material scarcity, when wool - considered a highly valuable resource - was difficult to source due to the absence of sheep farming in Italy. To address this issue, Prato's entrepreneurs devised a system for reclaiming and reprocessing wool from discarded garments, turning "rags" into high-quality textiles long before the concept of a circular economy even existed.

The history of the Biella district in textile recycling would seem to be more recent, as local industries have always relied on the import of high quality wool and animal fibres, therefore mainly from Australia, New Zealand and South America. In reality, the art of recycling what we now call post-industrial waste has always been practised, as during the centuries of development of the Biella textile industry, an attempt has always been made to reuse and reprocess waste from the various phases of the supply chain, reintroducing it into the process itself, possibly in phases preceding the one that generated the waste, or in different processes. An example of this is the use of waste from the combing phase of a worsted wool cycle, consisting mainly of short fibres, as raw material for a woollen cycle.

The expertise of the districts spans from the collection and sorting of textile waste – a crucial first step – to wool recycling (and cotton in smaller quantities), managing blended fibers, and developing high-value applications for recycled textiles. However, the broader objective is to position these districts as leaders in systematic circular practices that can be expanded to other regions and new materials within the European textile industry.

A report connecting history, present and future

This report aims to present a comprehensive overview of the **best practices in textile recycling** developed over decades by the key players in the wool industry within the Prato and Biella districts. However, it also looks forward, identifying opportunities to **systematize processes, address current challenges and adapt to future needs**. This has been achieved by conducting a robust data collection effort, including **interviews with 36 industry stakeholders and companies**, who were asked to provide data and information to:

- Reconstruct a more realistic flow chart of the mechanical recycling processes and its preparatory activities, taking into account the various origins of textile waste (post-industrial, pre-consumer and post-consumer).
- Identify which textile recycling materials are most in demand, referred to as "**families of textile waste for recycling**" (more details in Chapter 3).
- Quantify current processing volumes and explore future capacity potential.
- Identify and analyze the current bottlenecks and critical issues that hinder the development and efficiency of recycling processes, slowing progress even in historically significant districts such as Prato, known for large-scale textile recycling and Biella, renowned for its quality-focused approach.

A Data-Driven approach (Interviews, insights and strategic analysis) to inspire broader Textile recycling

The report presents the findings of the interviews, supplemented by internal analyses and technology mapping efforts conducted by the project team. In particular, Chapter 4 offers a strategic overview of textile recycling technologies, ranging from low Technology Readiness Levels (TRLs) to industrially consolidated solutions. This chapter draws directly from a dedicated Technology Scouting for Textile Waste Management report developed within the RegioGreenTex project, which maps key actors, processes and innovation trajectories across the European textile recycling ecosystem. While Chapter 4 provides a curated synthesis of its results, the full scouting report stands as a complementary technical resource for stakeholders seeking a more detailed understanding of available and emerging solutions. Similarly, Section 2.5 contextualizes the evolving regulatory landscape within the European Union, which is critical for textile districts and SMEs as they navigate certification processes and regulatory compliance that could reshape recycling workflows.
While the report primarily focuses on wool recycling, it also aims to abstract and generalize key insights that can inspire the recycling of other textiles, such as cotton, which is already being recycled to some extent in these districts.

A major innovation introduced in Chapter 5 is the Textiles Index of Recyclability (TIOR), a methodology designed to evaluate how recyclable a textile waste stream is, based on its current material characteristics. This tool supports immediate decision-making by helping identify the most suitable applications for different material families and highlighting barriers to recycling.
Chapter 5 also presents two additional indices under development: the Textiles Economic Recyclability Index (TERI), focused on the cost-effectiveness of recycling, and the Textiles Recyclability Index (TRI), which looks ahead to a future where product recyclability is assessed from the design stage, guided by traceability and ecodesign principles.

Supporting the development of Recycling Hubs

The report also compiles a wealth of information that could be instrumental for the new **Recycling Hubs (ReHubs)** being established in Italy and Europe. These hubs are envisioned as central nodes within the recycling value chain, acting as intermediaries that connect collected materials to diverse value chains depending on their final applications. The idea is to centralize as much as possible the collection, selection and dismantling of complex waste, such as end-of-life garments, in order to increase both the quality and quantity of recycled materials.

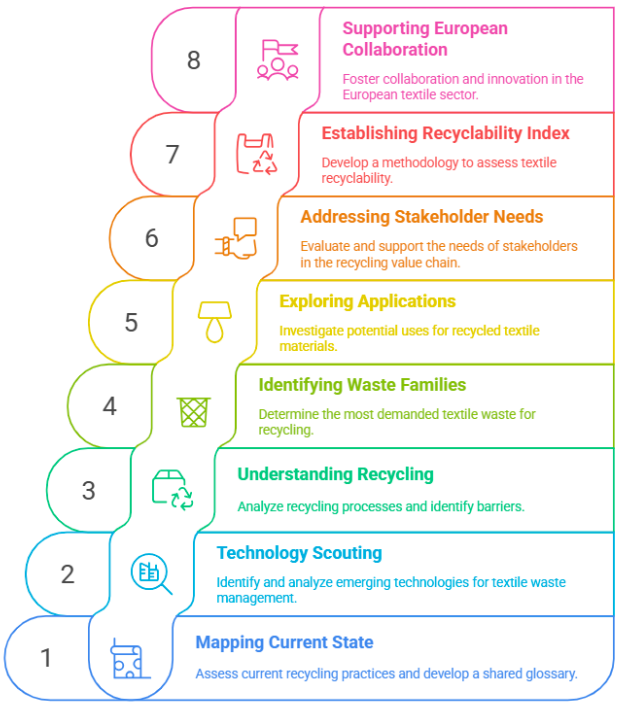
This centralization is further justified by the high level of investment required to automate these operations, and it could also serve as a catalyst for innovation and research in textile recycling. By leveraging the tacit knowledge of recycling professionals – often gained through years of hands-on experience – these hubs can significantly improve sorting precision and processing efficiency. Ultimately, the goal is to ensure that textile waste is accurately categorized and channelled into the most suitable recycling pathways, whether for fiber-to-fiber regeneration, non-woven applications, or downcycling processes.

Yet, in the framework of the **RegioGreenTex project**, the idea of a ReHub goes beyond the image of a single facility. It is conceived as a **two-layer system**: on the ground, physical infrastructures such as those currently under development in Prato and Biella, where textile waste will soon be collected, sorted and recycled; and above them, a shared, service-oriented layer designed to connect and empower these local hubs. This second level takes shape in the **Italy Greentex Hub (IGH)**, a national platform that offers transversal services: from mapping waste flows and developing decision-making tools like the TIOR recyclability index, to supporting certification and traceability, fostering training and skills, and enabling the exchange of knowledge across regions and industries.

In this sense, the Italy Greentex Hub is not a plant but a **platform**: a space where innovation, coordination and services converge to make the physical hubs more effective and future-oriented. Chapter 2 delves deeper into this dual architecture, while the Conclusions present a concrete proposal of macro-services for the IGH, built on the insights gathered through data analysis, interviews and field research.

1.1 The specific objectives of the report

Mapping the current state and developing a shared glossary



One of the foundational objectives is to create a comprehensive state-of-the-art assessment and a common European glossary for textile recycling. These tools are not intended to cover the entire spectrum of circular practices, but rather to serve as a solid and scalable starting point. The assessment begins with the collection of textile waste and follows its journey through sorting and all stages of the recycling process, with a specific focus on mechanical recycling. This choice reflects the long-standing expertise of the analysed districts, which have developed deep knowledge in managing textile waste streams and optimizing operations to produce high-quality mechanically recycled wool, also known as 'lana meccanica/riciclata'. Grounded in the in-depth analysis of the recycled wool value chain, the assessment provides a concrete lens through which to identify current challenges, solutions, and terminology. While specific to wool, the resulting insights and definitions offer a replicable framework that can be expanded and adapted to other materials and regional contexts. By standardizing practices based on real-world knowledge, the research supports a more coherent and collaborative approach to scaling textile recycling in Europe.

To enrich this state-of-the-art assessment and provide a broader strategic and operational outlook on textile circularity, a complementary report was developed within the RegioGreenTex project, focused specifically on **Technology Scouting for Textile Waste Management**. Led by the Biella-based team, this dedicated study maps the landscape of existing and emerging technologies for textile waste sorting, treatment, and recycling - ranging from mechanical and chemical solutions to AI-assisted sorting systems and integrated hybrid approaches.

Beyond describing individual processes or tools, the scouting study offers a structured analysis of key actors, technology readiness levels (TRLs), industrial scalability and the persistent gaps that hinder system integration and circularity at scale. Chapter 4 synthesizes the main findings of this work and translates them into strategic reflections tailored to the Italian and European textile context - especially with regard to the planning and coordination of future ReHubs.

The full Technology Scouting Report is available as a stand-alone resource and is intended to complement the current analysis, particularly for stakeholders seeking a deeper technical or innovation-oriented perspective on textile circularity.

Understanding Recycling practices and identifying Barriers

The research seeks to analyze how recycling processes are currently managed starting from the collection of textile waste that could affect all the subsequent activities of the value chain, highlighting the challenges faced in achieving a smooth circular process that produces high-quality recycled materials comparable to virgin materials. By addressing these barriers, the study aims to identify strategies to enhance the textile recycling rate within businesses and the material absorption by the market.

Identifying the most demanded families of textile waste for recycling

An additional objective is to identify the most demanded families of textile material for recycling among stakeholders in the Prato and Biella districts. Understanding these preferences is crucial for aligning recycling efforts with market needs, optimizing material flows and supporting the development of targeted applications and services within the textile recycling value chain.

Exploring Applications for Recycled Materials

Another critical objective is to investigate the current and potential applications for recycled textile materials. While strong emphasis is placed - both in this research and in evolving European legislation - on improving the input side of the value chain through effective textile waste collection and sorting, it is equally important to strengthen the output side. Identifying viable end uses for recycled materials is essential to ensure that collected waste is truly transformed and reintegrated into new products and markets. Without functional and scalable applications, even the most accurate and widespread collection systems cannot deliver a truly circular value chain. By highlighting the main obstacles and opportunities, this research aims to expand the scope of recycled materials and support their integration into both existing and emerging market sectors.

Addressing the needs of Textile stakeholders that work in the recycling value chain

The study places significant emphasis on understanding the needs and challenges of textile stakeholders in relation to recycling. This includes evaluating the role of the emerging Recycling Hubs, such as the one planned for Prato and for Biella and suggest a portfolio of services to support the textile recycling value chain effectively.

Establishing a Recyclability Index for textile and/or textile waste and a methodology for their measurement

Starting the development of a Textiles recyclability Index is a pivotal objective of the current study. This index should:

- Evaluate and classify different textile waste material families by their ease of recycling and the range of potential applications for recycled outputs
- Identify appropriate recycling technologies for each material type.
- Outline potential applications for recycled materials.

A major innovation introduced in this report is the **Textiles Index of Recyclability (TIOR)**, a methodology developed to assess the recyclability of textile waste based on its current physical and material characteristics, regardless of origin or upstream traceability. Its purpose is to support short-term, practical decision-making by guiding the selection of the most suitable recycling applications for different material families, while also identifying key barriers that limit recyclability.

In addition to TIOR, the report outlines two other indices currently in early conceptual development:

- **The Textiles Economic Recyclability Index (TERI)**, which focuses on evaluating the economic viability of recycling specific material families, taking into account factors such as processing complexity, potential value recovery and market conditions.
- **The Textiles Recyclability Index (TRI)**, a forward-looking tool that aims to assess recyclability from the very beginning of a product's lifecycle. By leveraging full product traceability and guided by ecodesign principles—such as mono-material design, disassembly strategies, and low-impact treatments—TRI envisions a system where recyclability can be embedded at the design stage.

Together, these three indices provide a complementary and evolving framework for addressing textile recyclability from multiple perspectives: immediate textile waste material management, economic efficiency, and long-term circular design.

Contributions of SMEs to Textile recycling

The research highlights the critical role of Italian SMEs in textile recycling. By mapping their contributions based on interviews with a selected sample of actors, the study explores: the most commonly used families of textile waste materials for recycling; the “average” value chain and the technologies applied to manage by-products and secondary raw materials; strategies to enhance SME participation in creating a green business ecosystem.

Aligning with European Legislation and Certification scenarios

A key objective is to evaluate how the textile value chains in Prato and Biella align with evolving European legislative and certification frameworks. By identifying gaps and opportunities, the study aims to position these districts as leaders in sustainable textile practices.

Supporting European Collaboration and Innovation

This report is integral to the broader effort of fostering collaboration and innovation in the European textile sector. By addressing key challenges and opportunities within the circular economy, it provides actionable insights that align with the objectives of the EU-funded project aiming to:

- Map the needs and potentials of circular economy implementation in diverse regions, offering a comparative analysis of the Prato and Biella districts as exemplary models of textile recycling practices.
- Build a dynamic textile recycling ecosystem by contributing to the foundation of a shared digital platform, underpinned by data-driven insights on material flows, recyclability indices, and stakeholder needs.
- Accelerate SME innovation in recycled textiles through the dissemination of best practices, methodologies, and emerging technologies identified in the report.
- Establish regional textile recycling hubs by providing a detailed understanding of the operational and strategic requirements needed to develop hubs aligned with the ReHubs initiative and EU textile strategy.

The insights into textile waste materials, families and processes presented in the current report are shaped by the perspectives of the interviewed stakeholders. The selected sample of participants inherently influences the types of materials and processes discussed, which may not fully represent the broader dynamics of the textile recycling ecosystem. This underlines the importance of diversifying future research samples to capture a more comprehensive understanding.

It is needed to underline that to optimize the scale and efficiency of recycling hubs, the research may continue to quantify the volumes of materials currently processed or potentially processable by stakeholders in Prato and Biella. This will inform decisions on the dimensioning of hubs, the management of local versus international recycling flows, and the strategic use of indigenous recycled materials.

1.2 Glossary

To better understand this report, a short glossary is provided with terms commonly used in the textile sector, particularly within the Prato and Biella districts with referring to the textile waste management.

Discarding	The act of intentionally setting aside or disposing of a material or product at any stage of its lifecycle, regardless of whether it has reached the consumer. Discarding can occur before its use or after use. In line with the EU Waste Framework Directive (2008/98/EC), a product is considered waste when its holder discards it, intends to discard it, or is required to discard it. Therefore, discarding is not limited to post-consumer actions—it includes decisions made by producers, brands, retailers, or even logistics operators to remove textiles from circulation.
Post-Consumer Textile Waste	Textile products that have been discarded after being used by the final consumer. This includes garments, home textiles, and other textile items that are no longer wanted, needed, or functional—whether due to wear, damage, obsolescence, or fashion trends.
Post-industrial Textile Waste	Post-industrial textile waste refers specifically to waste generated during the industrial manufacturing process (Ref. New EPR Regulations). (**By-product** - A substance or object resulting from a production process that is not the primary product but can still be used lawfully without being classified as waste, according to Article 5 of the EU Waste Framework Directive. In the textile industry, fiber residues or fabric scraps can be classified as by-products if they meet the legal conditions).
Pre-consumer Textile Waste	Pre-consumer textile waste encompasses materials discarded before reaching the consumer, including unsold stock. This category is significant in the context of circular economy strategies, as it represents materials that, while unused by consumers, have already consumed resources during production (Ref. New EPR Regulations)
Secondary Raw Material	A material that has been recovered from waste and reintroduced into the production cycle, replacing virgin raw materials. In textiles, this could be recycled fibers used to produce new yarns or fabrics
Textile Waste	All textile materials that are discarded at any stage of the product lifecycle, from production to post-use.
Waste	Any material or object that the holder discards, intends to discard, or is required to discard (EU Waste Framework Directive 2008/98/EC). In the textile sector, this includes production scraps, damaged goods, unsold stock, and used garments.

Building upon the definitions provided above and in line with the implementation of new Extended Producer Responsibility (EPR) frameworks at the European level, as well as nationally, there is a growing need to move beyond these broad categories and introduce a more detailed and operationally useful **waste hierarchy**. The table provided in this section aims to propose potential sub-classifications within each category, for instance, identifying waste streams such as yarns, tops, or fabric rolls under the post-industrial umbrella. This type of taxonomy would enable a more systematic and harmonized approach to waste sorting at the point of generation, which is essential for optimizing downstream processes across the value chain, from collection and logistics to reuse, recycling, and material recovery.

Such a classification is not merely a technical exercise: it holds strategic value for the entire circular ecosystem. Producer Responsibility Organizations (PROs), recycling hubs, and other actors along the textile value chain are actively awaiting the development of a clear and widely accepted waste hierarchy. It will facilitate compliance, improve traceability and enable more effective planning of sorting and treatment infrastructure. In this sense, the refinement of textile waste definitions and the introduction of a hierarchical framework should be seen as foundational steps toward the implementation of truly circular textile systems.

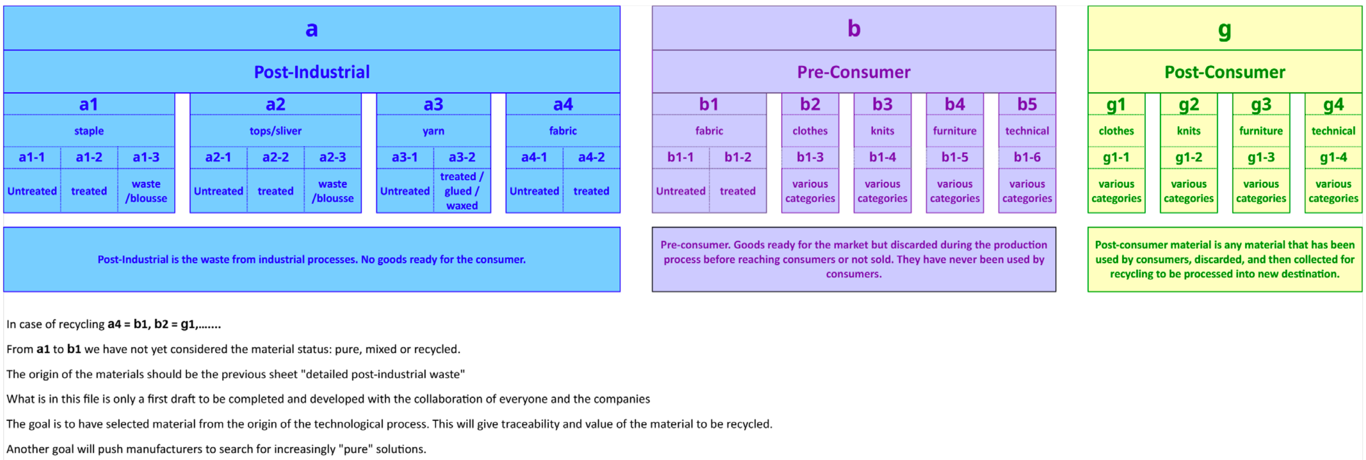


Figure 1: Simulated waste hierarchy and categorization model

2. Definition of the Context

As mentioned, this report focuses on the Italian textile districts of Prato and Biella, highlighting their historical and current contributions to textile recycling and circular economy practices. Given their unique imprint on recycling systems and sustainable innovations, these districts serve as a valuable reference point for understanding the challenges and opportunities within the European textile industry.

In the current section, we aim to provide a concise overview of the **key characteristics of these districts and how they operate within the context of sustainability and circularity**, mapping in details their recycling value chain, starting from the textile waste collection.

To better understand how Prato and Biella translate circular principles into operational practice, we have developed a detailed *value chain map* that visually captures the **transformation journey of textile waste into regenerated wool-based products**. Then, the description of the map, focusing specifically on the stages involved in mechanical recycling, which remains the dominant approach in these districts.

This description does not aim to be exhaustive but rather serves as a foundational reference for the chapters that follow. It provides the necessary background for understanding the structured flow of textile recycling in Prato and Biella, particularly regarding the re-elaboration of interviews (Chapter 3), the phases where advanced recycling technologies can be integrated (Chapter 4) and the underlying rationale behind the Textiles Index of recyclability and the other indexes (Chapter 5).

Much of this analysis draws from the extensive work carried out within one of the key activities of the RegioGreenTex project (Activity 1.3 – Work package 1), as detailed in the "*Report 1.3: Mapping and Gap Analysis of Value Chains for Sustainable and Circular Textiles*". This foundational report helped us shape the value chain representation and provided insights into the objective identification of gaps that hinder or slow down circularity across the textile value chain.

As the following sections demonstrate, many of these gaps are directly referenced and reinforced by the inputs gathered from the interviews conducted with key stakeholders in Prato and Biella. These interviews reveal not only existing bottlenecks but also strategic areas for innovation and improvement.

Secondly, the report builds on the activities developed within the Work Package 5 of the project, which focuses on the creation of five regional textile recycling hubs aligned with the ReHubs initiative and the EU textile strategy, among which, notably, the Italian one - Italy Greentex Hub. These hubs serve as testbeds for ecosystem-level circular solutions. The work in WP5 supports the development of investment strategies and validated plans for the ReHubs and the involved SMEs and strengthening the regional ecosystems around textile recycling.

Finally, it is important to note that any attempt to define the context in which these districts operate would be incomplete without also considering the **broader policy and regulatory framework** that is actively shaping the direction of textile circularity in Europe and Italy. While this report does not provide a full legislative analysis, it offers a reflection on how regulatory dynamics - both at European and national level - are perceived by local actors, and how they influence operational decisions, cultural mindsets, and investment strategies. This dimension is addressed in Chapter 2.5.

2.1 Mapping the End-of-Life Textile Value Chains in Prato and Biella and their approaches to Recycling

The textile districts of Prato and Biella represent two distinct but complementary models in the European circular textile economy. Both districts have built their reputations over centuries, yet their approaches to recycling and sustainability differ due to their historical specializations and industrial structures.

Prato is recognized as a global leader in recycled wool and textile waste management, with an integrated system that has evolved over more than a century. Its textile End-of-life and recycling value chains relies on close collaborations between different actors involved in the collection, sorting, recycling and reprocessing of textile waste, making it a benchmark for efficiency and sustainability in the sector. Prato's ability to adapt to changing market demands, regulatory shifts, and technological advancements has been key to its continuous growth as a circular textile hub. However, the district is currently facing challenges related to new regulations, increased pressure from brands for more transparent supply chains and shifts in global market dynamics that are redefining the industry's approach to sustainability.

Biella, on the other hand, has historically been known as a center of excellence for high-quality wool production and textile innovation. While its reputation has been built around fine wool manufacturing rather than large-scale recycling, the district has been progressively integrating sustainability principles and circular economy strategies. Biella's strength lies in its synergy between traditional manufacturing, research centers, and institutions, allowing for the development and adoption of advanced textile recycling technologies.

2.1.1 Mapping the Mechanical wool recycling value chain

The value chain map presented in this chapter illustrates the completed flow of processes essential for the transformation of textile waste in recycled wool. In this specific case, **the map highlights the key stages and operational steps that mechanically recycled wool undergoes to be reintroduced into a recycled textile-based product, beginning with the initial collection of textile waste**. While this mapping draws inspiration from the foundational framework of the value chain introduced by Michael Porter (1985), which focuses on the identification and organization of primary and support activities that generate competitive advantage within the firm, it does not aim to deconstruct each individual activity for example addressed to inbound logistic, marketing, etc... Instead, the aim here is to outline the main process stages relevant to the mechanical regeneration of wool. Today, however, the conceptualization of value chains has evolved to reflect broader, systemic dynamics. Contemporary approaches, such as the Global Value Chain (GVC) framework developed by Gereffi et al. (2005) and the growing literature on circular value chains (Bressanelli et al., 2018; Merli, Preziosi & Acampora, 2018) emphasize the importance of mapping not only activities but also the complex interrelations between actors, stakeholders, and the multidirectional flows of materials, information, and value. In this sense, while this report focuses specifically on the sequence of steps associated with the mechanical recycling of wool, future work should consider integrating these expanded models to fully capture the dynamics of circular textile ecosystems.

Thus, even though this map is comprehensive providing a clear framework for **understanding how the upstream processes of waste collection, sorting and directional flow toward recycling function within the system**, it is important to note that textile waste and scrap can originate from countless sources, leading to a nearly infinite number of recycling pathways. In other words, from the processes and activities within this highly complex value chain, multiple possible directions can emerge for textile flows, both in terms of the materials themselves, the technologies that can or want to be applied, and the final intended applications of the recycled materials. Therefore, this map focuses specifically on the processes relevant to the regeneration of wool through mechanical methods, rather than chemical or thermomechanical recycling.

The value chain is structured into **three main macro-areas**, each representing a crucial phase for the districts, in the transformation of textile waste into new materials and products.

Each macro-areas outlines sequential operational steps that, in daily operations and for certain materials, may be skipped or rearranged in order. In practice, some steps can be omitted or modified based on the specific characteristics of the material being processed, the needs of the recycling facility, or efficiency considerations.

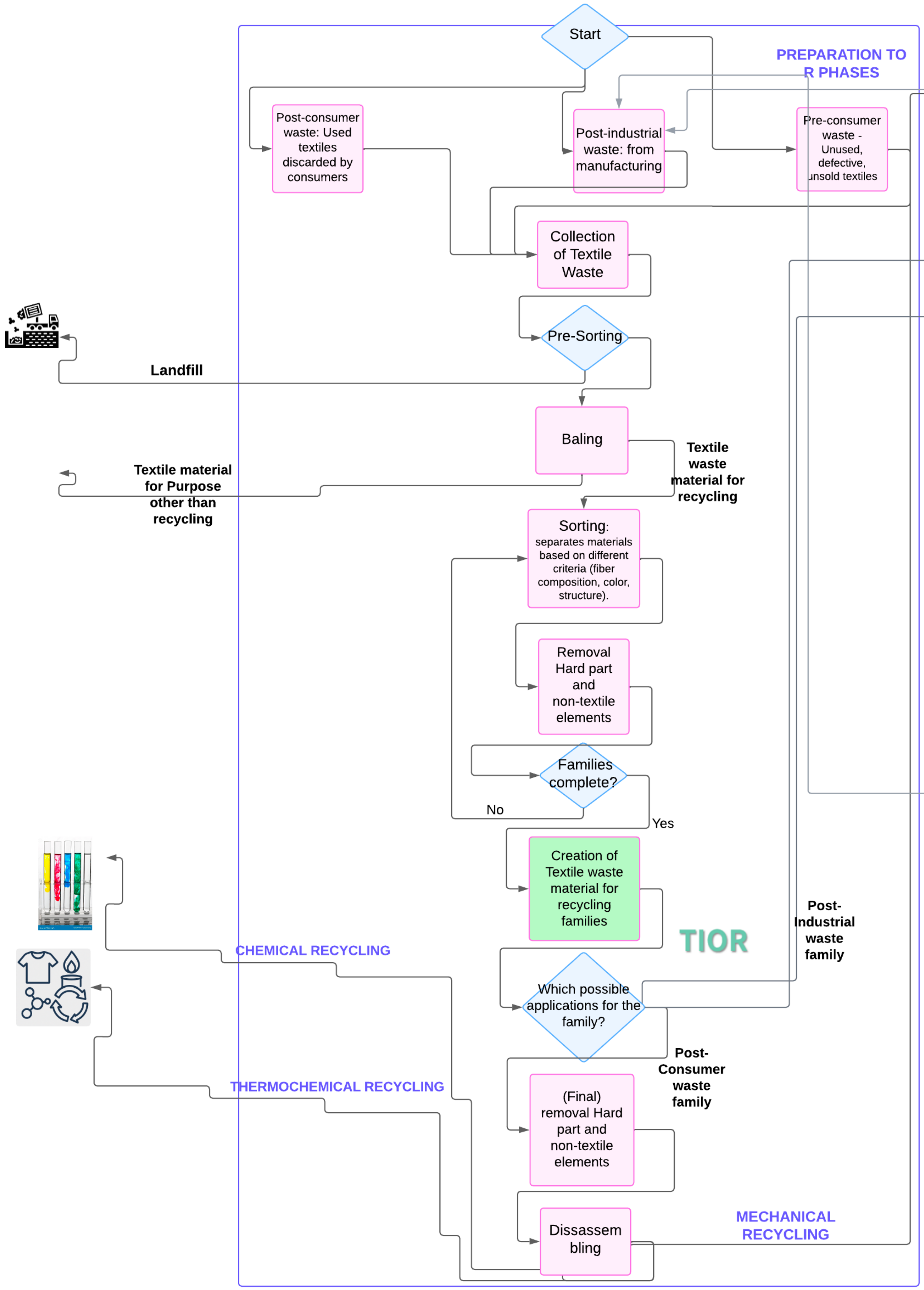
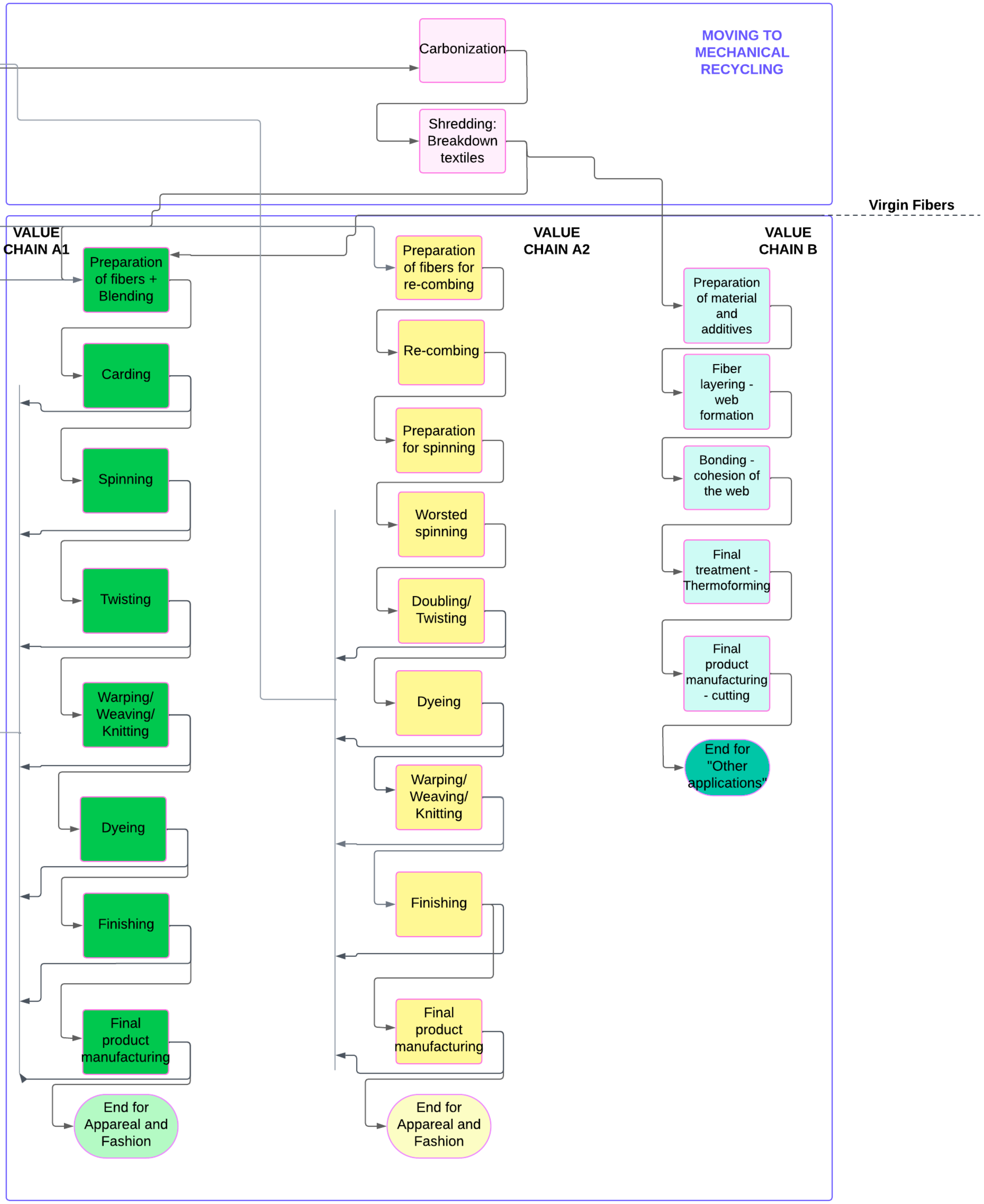


Figure 2: Mechanical wool recycling value chain



Click on this link to download the map

2.2 The foundations of sustainability in the Italian districts: Textile waste Collection and Sorting

The first macro-area involves the origins of textile waste, its collection and its pre-sorting. Understanding the lifecycle of textile waste requires distinguishing between post-industrial, pre-consumer and post-consumer waste. This topic is explored in greater detail in Chapter 3, through the lens of consortia, associations, and stakeholders directly involved in its management.

Post-Consumer Textiles collected and transported to Pre-Sorting centers. Post-consumer waste consists of discarded textile products that have reached the end of their use phase and are collected through organized municipal collection systems.

The structure of this collection varies depending on local regulations and municipal waste management strategies. Once collected, the material is transported to sorting centers, where the first key phase of processing, known as **pre-sorting**, takes place.

During the pre-sorting stage, trained personnel manually inspect each textile item to determine its most suitable destination. Based on this assessment, materials are directed toward one of the 5R pathways (refuse/reduce, reuse, repair, refurbish/repurpose, and remanufacture/recycle) or to landfill if no viable recovery option is available.

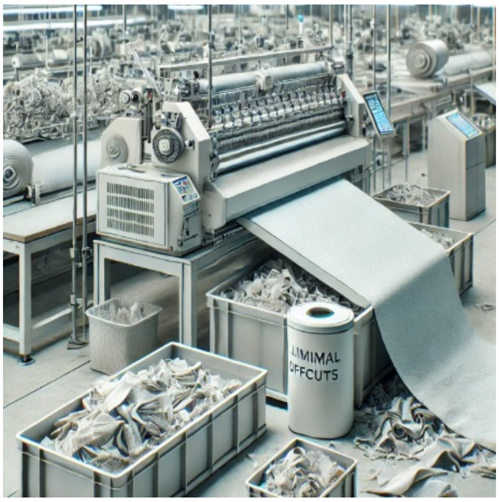
5R pathways	Main Description	Main Objective	Illustrative Case
Refuse/Reduce	choosing not to buy or use things that are not truly needed	Avoid waste generation.	Not buying unnecessary clothes
Reuse	using an item again for its original purpose, without the need for significant reprocessing or transformation	Extendproduct ulife.	Donating or selling used clothes
Repair	fixing broken or damaged items instead of discarding them	Avoidppremature disposal.	Sewing a torn seam
Refurbish/Repurpose	restore the original function of an object by replacing parts/create aew function for an object.	Extend the product's useful life or redirect it toward a newuse pathway..	Transforming old garments into bags or home accessories
Recycle/Remanufacture	turning waste materials into raw materials for new products/Rerestoring products to like-new condition.	Recover materialsfor nproducts.	Recycling textile waste structure into new fibres

Table 1: Actual Overview of the 5R Framework in Textile Circularity

For materials that are not disposed of in landfills or incinerated, the next step is compression into **bales**.

This process allows to reduce the volume of textile waste, facilitating its transportation and further processing. The pressed bales are then routed based on their most appropriate next phase, which may include:

- reuse/repurpose markets: some textiles are resold as second-hand clothing or repurposed for alternative uses;
- companies specializing in repair and reconditioning: certain items are directed to businesses that repair and refurbish garments to extend their lifespan;
- recycling pathways: Materials that are not suitable for reuse or repair proceed to secondary sorting, a more detailed classification process that prepares them for recycling. This stage is particularly central to our value chain map, as it directs textiles toward various recycling processes, such as mechanical fiber regeneration.



Post-Industrial and Pre-Consumer waste, on the other hand, consists of industrial textile scraps that have never reached consumers. This category includes post-industrial waste, originating directly from manufacturing processes, and pre-consumer waste, which consists of unsold products, defective items, or surplus inventory.

In Prato and Biella, due to a long-standing expertise in textile recycling, **companies have developed efficient systems for directly intercepting valuable post-industrial waste**, either reintegrating it into production or trading it with third parties. Some high-quality pre-consumer materials are highly sought after as they lead to premium recycled fibers, while others, unfortunately, are discarded due to market limitations, small production batches, or the absence of sorting technology at the source.

Sorting is a crucial operation within Prato's textile recycling industry. This phase takes place in the first processing plants, where workers, known as "cernitori", manually classify textile waste: their expertise allows them to assess the fiber composition, quality, and color of materials using sensory methods such as sight, touch, smell, tearing, or even burning fibers. This artisanal knowledge remains fundamental, although it is increasingly being supported by semi-automated sorting technologies.

The sorting process follows multiple criteria: section 3.4 explains this activity in more detail. Fiber composition is the primary determinant, differentiating between wool, cotton, polyester, and mixed fibers. Color is another key aspect, as grouping textiles by shade minimizes the need for additional dyeing. Other criteria include fabric structure (woven, knitted, or non-woven) and garment type (T-shirts, pants, industrial scraps). Additionally, geographical origin plays a role in fiber quality, influencing how materials are processed.

Sorting is not a single, isolated step but rather an **iterative and distributed** activity that takes place at multiple stages across the textile value chain. It begins with **pre-sorting**, a crucial phase in which textile waste is initially assessed and directed according to the logic of the **5Rs**: Reduce, Reuse, Repair, Recycle, Recover. For example, garments in good condition may be channeled toward reuse or repair initiatives, while lower-quality materials or those with complex compositions may be earmarked for recycling or recovery.

Once a material is directed along the recycling pathway (R of Recycle), sorting becomes more specialized and is repeated at various stages. For instance, dedicated sorting centers carry out large-scale operations on textile waste - post-consumer or pre-consumer flows that were not previously intercepted within the district - focusing on a broad categorization of materials by fiber type, composition, and condition. In many cases, especially when manual sorting is required, these operations are outsourced to countries such as Pakistan and India. These regions have become key hubs in the global textile recycling chain due to their availability of low-cost labor and well-established infrastructures for handling second-hand and discarded materials. Here, workers sort large volumes of textile waste by hand, often under labor-intensive conditions, allowing for more precise separation of fibers and fabrics. This step is crucial for enabling subsequent mechanical recycling processes, particularly when the materials are destined to be reintroduced into textile production cycles

Further sorting may then occur within the facilities of recycling companies themselves. A spinning mill, for example, that purchases recycled textile bales often performs an additional and more refined sorting phase, classifying fibers by color, fiber length, or blend ratio, depending on production needs and the specifications of the final product.

Once adequately sorted, the materials enter their respective recycling processes - mechanical, chemical, energy recovery. Mechanical recycling remains the backbone of Prato's and Biella's industrial system, particularly for wool. This process involves a sequence of mechanical operations that transform textile waste into new recycled wool-based materials, which are then used to produce carded wool-based products: yarns, fabrics, garments, accessories and a wide range of non-woven materials. Meanwhile, chemical recycling is gaining ground, especially for synthetic or blended textiles that are not suitable for mechanical treatment.

2.3 The evolving journey of Mechanical Wool production

Next comes **the second area of the map**:

Carbonization is a chemical process that can be optionally implemented to remove vegetable matter contamination from animal fibers, achieving enhanced purity levels when specific quality requirements or end-use applications warrant such processing.

The process involves treating the wool (either in loose fiber form or as fabric) with sulfuric acid, followed by drying and heating. This selectively burns off the cellulosic content while preserving the protein-based wool fibers. The charred residues are then mechanically removed, and the wool is neutralized and washed. Carbonization is particularly effective when dealing with wool blends contaminated with plant-based matter. However, it is not suitable for cellulosic or synthetic fibers, which suffer severe degradation or complete destruction during the process. Fibers such as cotton, linen, hemp, viscose, modal, lyocell, silk, acetateand nylon are either compromised or destroyed, making carbonization incompatible with many modern blends.

Mainly for ecological reasons, carbonization was first carried out in the Biella district and then in the Prato district. Carbonization was a standard phase in wool regeneration, especially for animal fibers contaminated by cellulosic or vegetal material.

The process has largely fallen out of use. This is due to a combination of factors: the decline in local wool regeneration activities, the closure of nearly all carbonizing facilities and a growing reliance on pre-carbonized wool imported from abroad. As a result, carbonization today represents a residual practice, applied only in specific cases where wool blends still contain destructible vegetable matter and require deep cleaning prior to mechanical recycling.

Shredding: breaks down the textiles into fibers, a process that varies depending on the material. Knitted fabrics, which have a looser structure, can often be shredded dry, while tightly woven or synthetic-blend textiles require moisture to facilitate fiber separation and reduce demage.

After shredding, materials are directed into two main recycling streams. In **closed-loop recycling (fiber-to-fiber)**, fibers are blended with virgin materials and reintroduced into the textile and fashion industry (**Value chain A**).

Alternatively, in **open-loop recycling (fiber-to-cross-sectoral)**, fibers are processed into non-textile applications, such as insulation, automotive components, and geotextiles (**Value chain B**).

Notably, Value Chain A does not rely exclusively on shredded materials: it also integrates high-quality post-industrial waste, such as in case of fiber, tops, or blousses, that can be directly reintegrated into spinning processes without undergoing shredding.

For **the third macro-area**: it focuses on the reprocessing phase, where recovered textile materials are transformed into new fibers and yarns. This stage begins with the preparation of textile materials from recycling, mechanically opened or collected as post-industrial waste, and continues through blending with virgin fibers (if required), followed by carding or combing, spinning, dyeing, and fabric formation.

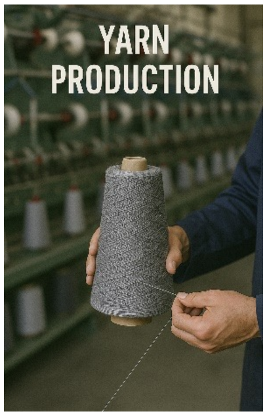
It encompasses both closed-loop recycling pathways (Value Chains A1 and A2), which reintroduce materials into the textile industry culminating in the production of new textiles or garments that contain mechanically recycled wool and open-loop pathways (Value Chain B), where fibers are processed into non-textile applications such as insulation, automotive components or geotextiles. The structure and technologies involved vary depending on the specific route, but all contribute to extending the lifecycle of textile waste and reducing dependency on virgin raw materials.

In **Value Chain A**, once the fibers are recovered and prepared, they undergo traditional textile processing. The first stage is carding or combing, where fibers are aligned based on their length. Shorter fibers are processed into carded yarn, while longer fibers are combed for smoother, finer yarns.

In the context of F2F mechanical recycling of wool, it is essential to distinguish between two parallel value chains, each rooted in the production specificities of the Prato and Biella districts. The first, referred to as Value Chain A1, corresponds to the carded process, while the second, Value Chain A2, is linked to the combed process. Both contribute to closing the textile loop, even if with different technologies, process logics and degrees of compatibility with recycled inputs.

The carded process (A1), typical of Prato, has historically and technologically evolved to accommodate short, regenerated fibers. Inputs include both post-consumer textile waste subjected to shredding and post-industrial waste collected from manufacturing processes. Once the fibers are recovered and prepared, they are blended with virgin material if needed and then **carded**, a process that disentangles, cleans and roughly aligns the fibers without achieving perfect parallelism. The resulting fiber web is transformed into yarn through low-twist **spinning**, producing bulky, soft and loosely structured yarns. This open structure not only enhances the thermal comfort of the final garments but also increases the efficiency of mechanical recycling. Carded yarns, due to their lower twist and compactness, are easier to reopen and defibrillate, enabling higher fiber yield and better quality in subsequent recycling cycles.

In detail, following the map:



- Carding: Fibers are disentangled, cleaned, and aligned to form a web. This technology is in use for shorter fibres that, then are processed into carded yarn, which has a coarser texture.
- Spinning: The fibers are twisted together to create yarn, with the degree of torsion influencing the yarn's strength, elasticity, and texture.
- Dyeing: This can occur at different points in the process—fiber stage, yarn stage, or fabric or garment stage—depending on the desired color consistency and fabric properties.
- Fabric Weaving: Yarns are either woven (interlaced structure for durability) or knitted (looped structure for flexibility and stretch) to form fabric.
- Finishing Treatments: The fabric undergoes processes such as softening, anti-shrink treatments, and surface modifications to enhance texture, durability, and performance.
- Garment Manufacturing: The finished fabric is used in clothing production, completing a closed-loop recycling cycle where discarded textiles are transformed into new, high-quality garments.

The combed process (A2), typical of Biella, is built around long, high-quality fibers used to produce fine, compact and durable yarns. Although this system was not originally designed for recycling, it has increasingly integrated circularity, especially through the reintegration of post-industrial waste, such as tops,slivers, semi-finished homogeneous fiber forms that do not require shredding. These low-degradation materials can be reintroduced at specific stages of the process, particularly during the preparation for combing or during re-combing, maintaining high final product standards while incorporating recycled content.

The operational flow of the combed system is articulated: after initial fiber preparation, carding is followed by combing, which removes short fibers and impurities to ensure optimal alignment. A second combing stage (re-combing) often integrates the recycled fibers. This is followed by worsted spinning, which applies a high twist to create strong, fine yarns. The process continues through doubling/twisting, dyeing (which can be performed at the fiber, yarn, or fabric stage), weaving or knitting, finishing, and final garment manufacturing.

The structural differences between carded and combed yarns have **direct implications for recycling performance**. Carded yarns are characterized by lower twist coefficients, coarser yarn counts, and greater tolerance of impurities. The resulting fabrics are less compact and more open, making them easier to reopen mechanically. Combed yarns, on the other hand, are made with long, parallelized fibers, subjected to high twist. These produce dense, smooth and durable fabrics that resist mechanical opening. Their compact structure and high twist reduce fiber length and recovery quality, while requiring more energy for processing.

A key technical parameter is the yarn twist coefficient (α), defined as:

$$a = \frac{\mathrm{T}}{\sqrt{\mathrm{N}}}$$

Where:

T = twist (twists per meter, tpm)

N = is the generic yarn count (Ne, Nm, Tex, e.g.)

where represents twists per meter and s the yarn count. High α values indicate tightly twisted yarns, which enhance strength but hinder recyclability. Lower α values, typical of carded yarns, promote fiber openness and easier mechanical reuse.

Given this, the Value Chain A1 in Prato is particularly aligned with circular economy principles due to its structural compatibility with regenerated fibers. The Value Chain A2 in Biella, though less accessible to post-consumer recycling, successfully incorporates high-quality post-industrial waste through technically advanced methods that preserve final product quality. Despite their differences, both chains contribute strategically to achieving textile circularity.

Value Chain B refers to the **open-loop recycling pathway**, where textile materials from recycling are not re-spun into yarn but instead reprocessed into **non-woven products**. This segment addresses fibers that are too short, heterogeneous, degraded or otherwise unsuitable for mechanical spinning of Value chain A1. Rather than being reintegrated into the textile-to-textile loop, these materials are redirected toward industrial applications where structural properties, rather than aesthetic or tactile qualities, are prioritized.

The non-woven production route bypasses conventional yarn-making and utilizes web-forming and bonding technologies to create functional materials. The process typically involves fiber opening, cleaning, and homogenization, followed by the formation of a fibrous web and subsequent stabilization through one of the following methods:

- Mechanical bonding, such as needle punching (where barbed needles entangle fibers) or hydroentanglement (where high-pressure water jets are used to consolidate the structure);
- Chemical bonding, in which adhesives or binders are applied to fix fibers in place, depending on the intended technical performance and durability;
- Thermal bonding, where heat or ultrasonic energy is applied to partially melt thermoplastic components in the blend, creating a fused and stable matrix.

Non-woven products resulting from this value chain are used in a wide range of industrial and technical applications, including geotextiles for construction and landscaping, insulation materials for the automotive and building sectors, furniture padding, filtration media and agricultural fabrics.

This open-loop pathway plays a critical role in maximizing the recovery potential of textile waste streams, especially for materials that do not meet the purity or fiber length requirements of closed-loop recycling.

2.4 The Recycling Hubs in Prato and in Biella and the new Italy Greentex Hub Ecosystem

Having outlined the existing value chains and core phases of mechanical recycling in Prato and Biella, it is equally important to explore how these districts are now organising themselves to scale up and systematise circular practices.

In this context, the creation of dedicated Recycling Hubs represents a strategic step forward, as Europe is guiding its regions and member states.

Within the RegioGreenTex initiatives, Prato and Biella chose to move toward the development of an integrated ecosystem for textile waste valorisation where the hub becomes the central node. This ecosystem is structured on two levels: regional infrastructures and a non-physical coordination and service platform known as the Italy Greentex Hub (IGH). These initiatives aim to integrate infrastructure, innovation, and local ecosystems, building capacity to meet both industrial needs and emerging regulatory challenges.

2.4.1 Local Recycling Hubs: Prato and Biella

The **Prato Textile Recycling Hub** is a pioneering initiative designed to transform the textile sector through a distributed model of innovation, infrastructure and collaboration, leveraging the full potential of the circular economy to turn textile waste into valuable resources, generate new business models, and support sustainable industrial growth. Grounded in the longstanding experience of the


Prato district in textile recycling, the hub integrates advanced industrial capacity with knowledge services and territorial networks, setting a new standard for circular economy practices in Europe.

At the heart of the hub is a major infrastructural investment based directly in Prato, carried out by a regional multiutility specializing in waste management named ALIA Servizi Ambientali S.p.a, enabling large-scale reuse and recycling of textile materials, as primary goal. The facility, currently under development with official opening planned for 2026, will feature:

- Automated sorting lines for post-industrial, pre-consumer and post-consumer textiles.
- Near-infrared (NIR) spectroscopy and AI-based technologies to identify fiber composition and material type.
- Processing capacity up to 33,000 tons per year of textile waste.
- Sorting for reusable garments, followed by industrial processes for mechanical or chemical recycling.

At full capacity, the hub will manage two main waste streams:

- 20,000 tonnes/year of post-consumer textile waste, corresponding roughly to the total demand across Tuscany;
- 13,000 tonnes/year of pre-consumer textile waste, including production and processing scraps, with around half originating from companies within the Prato textile district.

However, this infrastructure does not operate in isolation. It is part of a broader **distributed model**, where textile recycling is not confined to a single location but embedded in a network of local companies, service providers and research institutions.

Rather than centralizing all operations, the hub is designed to function through the **coordination of various actors** already active in the territory:

- Local companies that possess recycling technologies and expertise.
- Specialized research centers and innovation services that contribute knowledge, models, and methodologies.
- Sectoral experts with the capability to coordinate complex value chains and circular processes.

This approach maximizes efficiency, scalability and flexibility, enhancing Prato's historical advantage in textile recycling while enabling future-oriented innovation.

The Biella Hub is a strategic initiative for the circular economy and innovation in the textile waste management in Piedmont. It is aimed to enhance textile waste management, strengthening the district's role in the circular textile economy and establishing a regional and European model for the industrial recycling of textile waste. The Biella district is working on developing and scaling up its recycling capabilities, according to a model of cooperation among the main players, leveraging its century-long experience in the textile industry, with a particular focus on wool. What is emerging in Biella is not just a facility, but a living platform of support designed to empower every player in the textile recycling chain, from local SMEs to national actors, from start-ups to institutional partners.

The Biella Hub is based on a **collaborative model** in which all stakeholders contribute according to their area of expertise, with the goal of maximizing the impact of local actors — including key institutions, technical experts, training centers, research organizations, and businesses. The Hub aims to be recognised as a reference centre for issues related to the circular economy, recycling, and reuse, aligning with European standards and regulations concerning specific certifications and compliance frameworks.

Moreover, training institutions will be able to provide support in developing skills and advancing new circular economy practices, both by training new professionals and upskilling existing staff within companies. One of the most relevant players is **A2A Ambiente SpA** (plant operator, regional multiutility), which is implementing an experimental plant that integrates:

- advanced automated sorting technologies by material composition, colour and shape with Near Infrared (NIR) spectroscopy and RGB cameras for material and colour identification,
- high-pressure air jets for physical separation of items,
- real-time programmable outputs and high precision rates.

The advantages of this innovative system are the recognition accuracy up to 95% (with an adequate database), high sorting capacity, flexibility in customizing the number of outputs, reduction of the environmental impact of the textile sector.

This system is capable of processing a wide range of materials, including cotton, wool, viscose, polyester, polyamide, acrylic, polyurethane, acetate, silk, and various blends.

The plant is under development, according to the below phases:

1) Experimental Stage: setup of a 1,500 t/year experimental plant (by 2025)
2) Pilot Stage: Expansion to 5,000 t/year capacity (by 2027)

3) Industrialization Stage: Full-scale plant with 20,000 t/year capacity (by 2029)

The implementation will also be done considering the development of a shared regulatory framework for EPR and the alignment with new EU rules on mandatory separate textile collection, the integration with local reuse networks and the possibility to establish dedicated consortia.

Among the key players contributing to the Biella Textile Recycling Hub ecosystem is **MagnoLab**, a cutting-edge industrial network born in 2022 from the contribution of several leading companies in the textile value chain, of which many are members of Po.in.tex. MagnoLab is able to support the development and testing of prototypes made from recycled materials, evaluate performance and feasibility, and enable industrialisation of circular products. Its collaborative model encourages synergy not only among businesses but also across sectors, expanding the reach and value of the Hub's activities.

According to the Protocol Agreement for the initiative to establish the first Italian Recycling Hub, signed in 2022, a group of key stakeholders, including public institutions, industrial bodies, research and training centres, operational and technical partners, and companies, is also involved in the Biella Hub.

From an operational perspective, among the most relevant activities to be implemented to support the companies, the Biella Hub has to work to define a set of product categories and a process framework for **the use of secondary raw materials derived from textile waste**.

This approach builds on methodologies already tested in other sectors, such as, for instance: geotextiles (used in agriculture, soil containment, etc.), soundproofing and insulation materials (for the construction industry), technical textiles (for automotive, construction, and furniture applications), new generation textiles (for apparel or industrial use).

2.4.2 Italy Greentex Hub: A National Coordination and Services Platform

In the two-level architecture mentioned above, where the ReHub comprises both a physical infrastructure - including sorting and recycling facilities - and a soft component, the **Italy Greentex Hub (IGH)** acts as an enabler of textile circularity through the Recycling Hubs. The IGH aim to become a distributed, service-oriented ecosystem that connects, supports and enhances the performance of physical hubs by offering transversal and strategic functions.

Conceived and structured within the RegioGreenTex project, the IGH operates across Tuscany and Piedmont but aims to expand to other Italian and EU regions. It focuses on transferring know-how, supporting SMEs, consolidating testing and certification services, validating technologies and applications and aligning the Italian system with European circular economy goals.

Its value proposition is to accelerate the creation of a competitive market for high-quality recycled wool and textile waste by:

- Developing and deploying tools like the **TIOR recyclability index** , which will enable the automatic classification of textile waste to direct it toward the most appropriate reuse or recycling pathway;
- Mapping textile waste flows (qualitative and quantitative). To ensure effective management of its distributed structure, It's important that the hub will undertake a structured mapping process focused on the local industrial district. This includes identifying the main actors and their technologies, mapping out textile waste streams by type, origin, volume, and characteristics, and developing a comprehensive Textile Waste Material Map to support logistics, data exchange, and regulatory alignment. A key aspect of this work involves assessing the recycling potential of different materials through a multi-criteria approach that considers fibre composition, structure, dyeing processes, and levels of contamination
- Creating a catalogue of recycling technologies and application routes;
- Piloting transformation processes (TRL 6–9) for innovative textile waste uses (e.g. insulation, packaging, composites);
- Supporting the validation of materials through technical labs and certification advisory;
- Promoting co-design workshops, prototyping, and market activation;
- Offering capacity-building services (e.g., IGH Academy, training, regulatory literacy);
- Enabling traceability and data infrastructure for interoperable textile circularity.

The IGH is also tasked with engaging actors not yet involved in RegioGreenTex, including SMEs, start-ups, designers and public authorities. This includes technical seminars, demo-labs for material testing, matchmaking events, participation in trade fairs, and direct outreach to industry decision-makers. The hub is designed to be a permanent, innovation-driven reference point for the Italian textile system, fully interoperable with other EU ReHubs, centers of excellence, and consortia.

The hub will also serve as a dynamic platform for capacity building, designed to attract and cultivate new skills in textile sustainability and circular economy practices. It will promote and encourage the transfer of advanced knowledge to companies that are either already involved in or currently transitioning toward circular production models.

The IGH is also envisioned as a reference center for aligning with evolving European regulations and directives in the textile sector, particularly those related to sustainability, extended producer responsibility, and circular economy strategies. As EU policies increasingly emphasize the 5Rs the hub will play a key role in supporting companies in interpreting and implementing these requirements. By staying at the forefront of regulatory trends and fostering compliance-driven innovation, the hub will help the local industrial ecosystem remain competitive, resilient, and aligned with Europe's transition toward a low-impact, circular textile economy.

Taken together, the physical infrastructures of Prato and Biella and the Italy Greentex Hub define a synergistic architecture. The former provide operational capacity for sorting and recycling, while the latter provides strategic services, coordination and cross-regional support. **This model addresses Italy's need to shift from fragmented, district-level practices to a more structured and integrated textile circular economy.**

Thanks to their complementarity, these hubs will support the scalability of pilots, the standardization of certification, and the emergence of business models based on circularity. They are designed not only to process waste, but to serve as **living laboratories** where industrial actors can test, validate, and scale sustainable practices. Through this, Italy positions itself at the forefront of Europe's circular textile transition, combining heritage, industrial capability and systemic innovation.

Crucially, the hub's long-term success depends not only on its ability to collect and process waste, but on its capacity to identify, support, and coordinate new applications for recycled textile materials. By fostering their integration into other sectors — such as construction, automotive, or furniture — the hub aims to actively prevent becoming a passive accumulation or dispatching center, and instead operate as a catalyst for high-value, circular reuse. Without this strategic focus, there is a risk that the facility could evolve into a new type of landfill — an outcome fundamentally at odds with the principles of the circular economy.

This report, and the broader study it initiates, represents a foundational step in this direction. It provides the first structured inputs and analytical frameworks needed to guide the hub's evolution, ensuring that future developments are data-driven, sustainability-oriented, and fully aligned with both local industrial realities and the strategic objectives of European circular economy policy.

2.5 EU/National Sustainability Regulations for Textile and Fashion industry as a Double-Edged Sword: between urgency and alignment

Also understanding the legal and regulatory context is essential to interpret how industrial textile districts like Prato and Biella are reacting to the transition toward circularity. While this report does not aim to provide a comprehensive legal analysis, it does offer a lens to understand how certain gaps and actions - both technical and cultural - shape the current positioning of companies and stakeholders. The perception of risk, the speed of reaction, and the readiness to innovate are all influenced by how companies interpret and internalize the new policy direction coming from the European Union.

As the EU rapidly advances its circular economy agenda, the textile sector is entering a phase of structural transformation. New legislative frameworks, from Ecodesign and EPR to Digital Product Passports and End-of-Waste criteria, are redefining what it means to design, produce, and recycle textiles in Europe.

From the perspective of local actors, however, this shift is met less with alarm and more with measured pragmatism. A recurring sentiment is that **change is nothing new**. Over decades, these companies have learned to adapt shifting markets, resource scarcity, and evolving standards. Regulations, while increasingly complex, are approached as just another challenge that is important, but not overwhelming. There is a widespread awareness that much remains uncertain, and that only once the rules become concrete will it be possible to assess how to move. This attitude is a typical sign of resilience. Companies are used to listen, but not to overreact. Many feel that the real mechanisms of these policies - especially EPR, Eco Design and End-of-Waste - are still too ambiguous to justify major strategic shifts.

At the same time, different sentiments coexist within the districts. Some actors are already moving forward in small steps, **anticipating change by observing signals from large clients, especially brands, who are beginning to demand new standards**. Others remain hesitant, mainly due to a lack of information or cultural readiness. These are the companies most vulnerable to future disruption: they struggle to grasp the meaning of this transition and lack the tools to design a strong roadmap. Finally, there is a group of innovators - visionary and optimistic - who see in regulation a new phase of transformation and approach it with the same adaptive mindset that has long characterized the identity of these territories.

What creates friction, however, is the dynamic between brands and the rest of the value chain. Many producers observe how brands are moving ahead unilaterally, setting rules, timelines, and expectations without meaningful coordination. The risk is that legislation becomes a tool used by brands to reinforce compliance downstream, while upstream actors are left to adapt after the fact, often without fully understanding the rationale behind the requests.

Another structural issue is the misconception that the private sector alone can carry out the circular transition. A truly sustainable and regenerative model will not succeed unless the entire system moves in sync. National governments, municipalities, infrastructure providers and procurement agencies must all play their part. Water, energy, waste services, and public tenders must be aligned with the same vision. Otherwise, even the most virtuous companies will find themselves swimming against the current.

Circularity requires not just business compliance, but institutional co-responsibility. Without it, even the best regulatory ambitions risk becoming isolated exercises.

Other relevant reflections collected within the textile actors for the Circular Transition:

- Legislative ambition must meet operational reality.
  Regulations that demand virgin-like purity or performance from recycled fibers can unintentionally push them out of the market. Criteria must be adapted to real recycled inputs.
- The middle of the value chain is too often silent.
  Sorters, shredders, recyclers, the actors who process waste into new materials, are central to circularity. Yet their voices are still marginal in policy design.
- Waiting is not a strategy.
  While many SMEs prefer to postpone decisions until rules are finalized, this passive stance could slow down their long-term competitiveness; especially if compliance becomes a market access condition.
- Without downstream demand, upstream efforts stall.
  Collection, sorting, and recycling will only scale if regulations are paired with strong public procurement policies, incentives for using recycled content, and eco-design norms that ensure real recyclability.

2.5.1 Navigating the legal landscape: a living map of evolving norms

This regulatory scenario is complex and constantly evolving, as above remarked. For this reason, rather than attempting to analyse the full legal framework within the report, we refer readers to a curated interactive tool that offers guidance on where and how to explore the relevant legislation.

Wherever this report mentions or refers to regulatory drivers - both European or national - this map is intended as a simple navigation aid. It does not aim to replace legal analysis, but to direct users toward the official sources and institutional references behind the strategies, regulations, and directives currently shaping the textile sector.

The interactive map is kindly shared from a recent work (May 2025) developed by Next Technology Tecnotessile and the Lab Service Design, Università degli Studi di Firenze, as part of the study *"**Strategie di Eco-Design**"*, conducted within the framework of the RegioGreenTex project.

Figure 3: Interactive map of EU regulatory scenario

(by Next Technology Tecnotessile and the Lab Service Design, Università degli Studi di Firenze, "Strategie di Eco-Design", RegioGreenTex project, (May 2025)

3. How does the Value Chain of the Prato and Biella Di stricts take care of Textile Sustainability? The voices of the main actors

3.1 Analysis on Field: Interview Results

To provide an in-depth exploration of the textile recycling ecosystem in the Prato and Biella districts, this study integrates extensive desk research with a robust field analysis.

At the heart of this research are **36 interviews** conducted with a carefully selected panel of key companies and entities that are main actors of the value chain (textile recyclers, waste producers, sorters, waste collectors) and stakeholders (including industry associations) primarily from the Tuscany and Piedmont districts. Their insights allowed us to closely examine the practical functioning of textile recycling - both past and present - within this dynamic industrial hub, revealing strengths, weaknesses, and areas for potential improvement.

A key objective of the field analysis was to map the phases involved in the preparation and processing of textile waste materials for recycling (the value chain mapping presented earlier is one of the results), identify the main flows of textile waste, trace its origins and uncover the most common operational challenges faced by industry actors. Crucially, the interviews also sought to identify which textile waste materials for recycling are currently the most in demand, most purchased and most valued by companies in these districts, based on their specific end-use applications. These range from fiber-to-fiber recycling initiatives to nonwoven textile production using recycled inputs, as well as highly innovative applications emerging in niche segments. This qualitative evidence helps explain why certain materials are preferred over others, offering deeper insight into the criteria that drive material selection in the context of circular textile manufacturing.

To achieve this, we designed a **targeted questionnaire** (Annex 1) featuring both open-ended and closed-ended questions, with a stronger emphasis on open-ended queries to encourage detailed and nuanced responses. The questionnaire was specifically tailored to different actors within the value chain: companies involved in either processing recycled textile materials, producing them, or both. Notably, some companies in Prato and Biella demonstrate a self-contained, internal circular economy by handling both production and recycling. Additionally, a separate set of questions was crafted for entities engaged in activities such as collection, sorting and other treatments/services that complement or complete the recycled textile value chain.

Thanks to our extensive network within the districts, we were able to directly reach the key individuals and organizations to be interviewed, supported also by two trade associations that guided us to key stakeholders in the area on the topic of recycled materials. Appointments were scheduled starting from June 2024 either in person at company sites or, in some cases, through virtual meetings. The interviews were intentionally conducted in a “soft” and conversational manner, fostering a comfortable, natural dialogue and ensuring a smooth flow of information. All interviews were transcribed and subsequently reworked for analysis.

This section synthesizes the insights gathered, with each subsection representing a synthesis of responses to one or more related questions from the questionnaires, which are included as annexes to this report. The result is a rich and detailed account of the current dynamics, challenges, and opportunities within Prato and Biella textile recycling sector, offering a valuable foundation for understanding its potential for sustainable innovation.

The following sections present the analysis and synthesis of data collected through interviews with actors and stakeholders in the textile districts of Prato and Biella. The interviews were designed to explore the complexities of textile recycling processes, with questions tailored to specific categories of companies.

For confidentiality reasons, no individuals or organizations involved in the fieldwork are mentioned by name or identified through their business names. Moreover, the analysis aims to highlight common patterns and systemic insights rather than focus on individual cases, in order to avoid overemphasizing specific actors and ensure a balanced interpretation of sectoral dynamics.

This approach also reflects the exploratory nature of the research, which seeks to capture emerging trends and challenges without prematurely attributing them to particular entities.

3.1.1 Representation of the interview sample

The interview panel comprised a total of **36 actors** directly or indirectly involved in textile recycling processes across the Prato and Biella districts. Specifically, 15 companies operating in the recycling sector within the Prato district and 15 companies based in the Biella district - and surrounding areas - were interviewed. These companies represent a broad spectrum of core activities within the recycling value chain, ensuring a diverse and representative sample.

IIn addition to these, the panel included 3 **waste collection operators**: one operating at the regional level in Tuscany and two with operations spanning the national level. Their inclusion provides critical insights into the upstream dynamics of textile waste flows and sourcing strategies. Two of these operators are **Producer Responsibility Organizations (PROs)**, collective entities established by producers to comply with Extended Producer Responsibility (EPR) obligations. In the textile sector, PROs will play a pivotal role in financing and coordinating waste collection, sorting, reuse and recycling on behalf of brands and importers, ensuring compliance with EU and national regulations and supporting the transition toward more transparent and circular end-of-life management systems.

Furthermore, **three key stakeholder from the Prato district**, industry associations actively engaged in supporting, coordinating and representing textile companies in the recycling sector, were interviewed. These stakeholder play a strategic role in the local ecosystem, collecting needs from member companies, fostering collaboration and seeking systemic solutions. Their perspective added considerable value to the research by providing a comprehensive overview of the structural and strategic challenges faced by the district.

A key finding is that it is not easy to categorize companies into a single operational model. Most of the interviewed firms operate simultaneously as clients and sub-suppliers within the recycling value chain (waste producers and recyclers), with the latter role being more prevalent. Many collaborate with major brands as direct suppliers, while also subcontracting specific processing steps to other specialized firms.

This dynamic illustrates the complex and interconnected nature of the value chain in the textile districts. When asked whether their operations involve generating post-industrial waste, processing textile waste, or both, the majority of companies reported engaging in all these activities. They are not merely recyclers or producers of recyclable waste—instead, they often combine both roles. Through their own manufacturing processes, they generate post-industrial and pre-consumer waste, which they may then process or outsource, while also sourcing and using post-consumer recycled materials in the production of new textile products. This dual approach reflects the districts' commitment to maxime resource utilization and minimize waste, making it a leading example of circular economy practices[1].

The panel includes companies that handle textile recycled materials from various sources, including Post Industrial, Pre-consumer e Post-consumer waste. In the Biella district in particular, companies focus primarily on post-industrial and pre-consumer materials and to a lesser extent on post-consumer textiles.

This variety ensures that the research reflects a comprehensive and nuanced view of the district's recycling ecosystem.

[1] *Notably, one of the interviewed entities is currently active only as a waste producer, not yet involved in any recycling operations.*

Region	N° of Interview	Core business of the interviewees	Post-Industrial	Post-Consumer
Tuscany	1	Non-woven products Manufacturing	X	X
Tuscany	2	Yarn Manufacturer	X	X
Tuscany	3	Fabrics Manufacturers (only recycling products)	X	X
Tuscany	4	Recovery and upgrading of post-industrial textile waste	X	
Tuscany	5	Fancy yarn manufacturer, especially for knitwear	N/A	
Tuscany	6	Recovery of textile waste and shredding		X
Tuscany	7	Finishing of yarns and textile fibers	X	
Tuscany	8	Yarn Manufacturer (only carded products)	X	X
Tuscany	9	Carded yarns spinning [third-party processing]	X	X
Tuscany	10	Fabrics Manufacturers	X	X
Tuscany	11	Companies association	N/A	
Tuscany	12	Spinning [third-party processing]	X	X
Tuscany	13	Warp processing [third-party processing]	X	X
Tuscany	14	Fabrics Manufacturers [third-party processing]	X	X
Tuscany	15	Twisting Yarn processing [third-party processing]	X	X
Tuscany	16	Yarn processing [third-party processing]; Yarn Manufacturer	X	
Piedmont	17	Dyestuff manufacturer	X	
Piedmont	18	Yarn Manufacturer		X
Piedmont	19	Shredding, Yarn Manufacturer	X	
Piedmont	20	Shredding, Yarn Manufacturer	X	
Piedmont	21	Sorting, shredding, tops	X	X
Piedmont	22	Repairing / Reconditioning of Clothes	X	X
Piedmont	23	Yarn Manufacturer	X	X
Piedmont	24	Shredding, Yarn Manufacturer	X	
Piedmont	25	Weaving	X	X
Piedmont	26	Tops Manufacturer	X	
Piedmont	27	Manual Sorting of Yarn	X	
Piedmont	28	Manual Sorting of Fabric	X	
Piedmont	29	Sorting, shredding	X	
Piedmont	30	Sorting, shredding	X	X
Piedmont	31	Sorting, shredding	X	
Tuscany	32	Waste Collection, Future Textile Hub (collection management, sorting)	X	X
Italy	33	PRO	X	X
Italy	34	PRO	X	X
Italy	35	Companies association	N/A	
Italy	36	Companies association	N/A	

Table 2: Distribution of core business activities and processed material sources (post-industrial and post-consumer) across all interviewed actors, including companies, waste collectors, sorters and key stakeholders. The figure provides a comprehensive view of the sample's composition and roles within the textile recycling ecosystem. The distinction "post-industrial and post-consumer" adopted reflects the most common classification used by interviewees.

In the following, in the sections 3.2 – 3.11, the re-elaboration of the interviews is divided by themes and sub-themes, which are either related to specific phases of the value chain mapped in Section 2 or connected to the overall system that guides the entire value chain and supply chain.

To provide a comprehensive overview and enhance the readability of the key findings from the interviews, we also present a more **data-driven re-elaboration of the interviews through the following summary table**. The table is designed to give readers a clear and immediate grasp of the most relevant data collected during the interviews, serving as both a navigation tool and a high-level synthesis of the critical points explored in this section.

By presenting the key insights in a condensed, visual format, the table helps to highlight major themes, challenges and practices identified during the interviews. It focuses in particular on actors whose roles and activities align with the analytical categories defined in this table, thus allowing for a more structured and comparable representation across the district-level value chain.

It is important to note that the table reproduced here is a streamlined version, reporting only a selection of the most significant columns for immediate readability within the report. For a more exhaustive dataset, which includes a wider range of variables and detailed information gathered from the interviews, readers are invited to consult the extended table available online through the following link. This allows for deeper exploration of the data while keeping the report itself focused and accessible.

This dual-level presentation enables a better contextual understanding before delving into the detailed thematic re-elaborations that follow in the subsequent paragraphs.

Then, another relevant aspect to highlight is that some interviews - specifically interviews 11, 32, 33 and 34 - are not represented in the table, as their contributions were more systemic in nature and did not align with the table's classification criteria. These interviews provided valuable cross-cutting insights on governance, coordination mechanisms and national-level challenges and are instead discussed in greater detail in the sub-sections that follow.

N° Interview	Core business/Main Operation	Origin of textile waste incoming [waste or by-product]*	Families of textile waste materials for recycling treated/purchased**	Characterization of waste - What information is available about the incoming material?	Laboratory Tests/Analyses on Incoming Material	Material Yield	Barriers to Acceptance
1	Creation of market-ready non-woven outputs.Thermo/Sound-absorbing panels Products and semi-finished goods for mattresses, furniture, and construction.	Post-Industrial Post-Consumer	- Post-Industrial materials from garment manufacturing, padding (mattress production), and furniture. - Generic post-consumer materials sorted by color and composition. - "Rossino" (mixed fiber scrap)	Limited certifications. REACH, OEKO-TEX® (when available). In general, the heterogeneity of the material obstacles the data availability	Random tests. Fire resistance, acoustic/thermal absorbing	Acceptable yield loss: between 6% and 15%; ideal yield loss below 6%.	Material must be free from impurities (e.g., coffee cups, plastic stirrers, general waste); scraps should preferably be light-colored; polyurethane content must be below 20%; no dust contamination is tolerated.
2	Yarn production/Spinning	Post-Industrial (consolidated parterships) Post-Consumer	Cashmere, Wool. Affiliated company treats Eco-cashmere (85%) and wool (15%, max 17 micron) from Italy/EU, India, America	Color, fineness, weight	Random tests for chemical content, especially APEOs	High yield (8-10% loss for carding, 5% for combing); waste is minimized through re-use	Presence of wool in recycled cashmere treatments; high APEOs content
3	Fabrics Manufacturers (only recycling products). Sorting, spinning, weaving	Post-Industrial Post-Consumer	Virgin and recycled materials, including wool, polyester, and blends: - Most common blend: 85% WIO (Wool in Other) and 15% AF (Acrylic Fiber). - Material types: Tops, Laps, Blousses, Free of hard or removable parts. - Post- industrail and post-consumer waste from Australia, New Zealand, Far East through traders of Turkey, India.	Composition and fineness of fibers. No consistent data from all suppliers.	Chemical analysis including APEOs levels; fiber properties, REACH compliance	96% to 99%	Color variability, yarn count, dead fibers
4	Recovery and upgrading of post-industrial waste from textile production	Post-Industrial	"soft waste" (=fibers, blousses, tops) from combing and carding processes	Fineness, Color, Vegetable cleanliness, Origin, Composition	Tests for fineness and average fiber length to confirm match with sample. REACH compliance	High	Material must be clean (low vegetal content), appropriate fineness, color consistency; samples are requested prior to purchase
5	Combed spinning mill (filatura a pettine)	N/A	No incoming recycled fibres: the company treats only virgin materials, only some chemically recycled filaments. Virgin, natural and high-quality fibers. Typical compositions: Wool-Cotton/Viscose, Cotton + Polyamides/Polyester. Virgin Material Purchases: Animal Fibers (36-37%) - Wool, Alpaca, Mohair. Cellulosic Fibers (36-37%) - Cotton, Viscose. Polyamide Fibers (16-18%) - Used to enhance the strength and elasticity of textiles.	Not applicable	Not applicable	95%	Mixed fibers, small lot sizes limit recyclability.
6	Sorting.Shredding. Traders of textile waste materials	Post-Industrial Post-Consumer	- Post-Industrial and post-consumer textile waste, mainly from Prato districts (garments manufacturers) - Post-Industrial and post-consumer rags, mainly unusable in high-end fashion. 90% of the materials are not usable in F2F	Any technical documentation accompanies raw materials	Not specified	Not specified	Poor market, limited infrastructure for further recycling; inputs highly mixed = low-value.
7	Needle-punching	Post-Industrial	100% Cellulosic fibers, 100% Wool, minor amounts of Wool/Nylon, Wool/Acrylic blends.	No technical sheet or information received; sometimes impurities like cups found in the material	Not specified. Based on post-industrail origin and conformity	Not defined due to artistic/lab-like processes; yield loss depends on creative trials. But in general waste is	Only constraint is needle-punching ability
8	Yarn Manufacturer (only carded products). Carding Spinning	Post-Industrial Post-Consumer	Wool (preferably >85%). -15% Post-industrial (Combed and carded yarns, knitting or garment scraps); 85% post-consumer materials; - 20% of 60 tons: synthetic fibers. 15% from Eastern Europe or Italy, 85% from the U.S.A., Northern Europe, and Japan.	Geographical Origin, Compositions, Eco-toxicological Properties, APEOS	For input compliance with APEOS and eco-toxicology (Periodic testing)	4-5% per batch	Fiber composition (preferible wool >85%), Post-Industrial/Consumer origins, certifications
9	Third-party company focused on spinning and carding operations	Post-Industrial Post-Consumer	- 100% Wool, Wool - Polyester 80-20, Wool - Nylon 70-30, Wool - Cotton, Wool - Viscose Blends of wool, synthetics, and tailoring scraps. Mostly provided directly by the final client.	Information on composition and some eco-toxicological data (e.g., red color and amines), GRS certification, supplier name, Quantity, Title.	Chemical analysis of oils, REACH compliance	4–5% waste (avg.); contamination 2–5% per batch	Presence of cellulosic fibers, lack of clarity in certifications
10	Shredding Spinning	Pre-Consumer Post-Consumer	Selvedges, yarn ends, 'blues' from subcontractors, regenerated cashmere	In many cases, technical data sheets are not available; in others, the composition is guaranteed at the source	Tests for Amines, APEOs, PFAS, composition. Internal quality assessment	Not specified	Fiber purity, composition, presence of hazardous substances,Blends, cellulosic fibers, traceability, technical data sheets.
12	Third party Spinning	Post-Industrial Post-Consumer	Virgin and recycled textile fibers: presumed mainly post-consumer recycled material (not specified directly). The client only provides the composition to work with and the type of structure to achieve.	Client-provided information. No data beyond bales of waste material - only if it is GRS certified	GRS compliance; fiber cleanliness	91% (9% waste rate)	Fiber cleanliness and lenght, compliance with GRS standards
13	Third-party Weaving	Origin (post-consumer/post-industrial) not specified because not considered relevant by the company	Cotton open-end yarn and linen for furniture sector	Provided by the client per order, only for operational needs (Composition, processing type, GRS)	None specifically reported	97–98% (2–3% loss rate)	Complexity in certification and waste collection
14	Third-party Weaving	Unknown, information not provided by client	Tri-blend (30% wool, 30% acrylic, 30% other fibers), 80-20 Blend (80% wool, 20% other), Pure wool, Poly-cotton blends, Recycled polyester	Only basic details such as GRS certification, lot numbers, Fiber fineness, and color	Annual certification costs (€7-8K), primarily GRS requirements	92-94% (6-8% loss rate)	High cost of disposal and bureaucracy required for waste handling; lack of market demand.
15	Third-party twisting (post-spinning process to increase yarn strength or create special effects)	Origin (post-consumer/post-industrial) not specified because not considered relevant by the company	Wool cashmere polyester nylon viscose	Little importance placed on source or type of material; basic information like fiber type is known	Martindale and abrasion testing; focus on aesthetic and technical parameters	Not explicitly stated; appears low	High disposal and transportation costs; lack of differentiation; regulatory inefficiencies
16	Production of textile ribbons and narrow fabrics (woven or knitted)	Mainly from internal production processes (own offcuts, yarn remnants), plus limited use of externally sourced recycled cotton	Cotton, polyester, nylon, mohair – including some recycled cotton	Not specified	Not regularly conducted	Not specified in value, but high	High cost of certifications, lack of shared infrastructure, low volumes, disinterest from designers
17	Chemicals for finishing and dyeing	Post-Industrial Pre-Consumer Post-Consumer	Cotton, Fabric	Certified 100% Cotton	No	1	GRS and Oekotex Certifications Required
18	Spinning	Pre-Consumer Post-Consumer	Recycled PES and PA (10 PES e 5 PA, fibra 100% entrambi (quindi puri).	100% PES and PA fibers	No	N/A	GRS Certifications Required
19	Shredding Carding Spinning	Post-Industrial Pre-Consumer	90% Aramidic 10% other chemical fibers for technical applications Pre-consumer Waste.	Trust in suppliers, occasional sample analysis	Fiber compositionand length	17-25% loss	No fibres with altering finishes

* The category of pre-consumer waste such as unsold goods or warehouse remnants is not explicitly mentioned in the column definitions. This is because, at the time of the interview, respondents primarily considered either production waste or used garments as textile waste.

** Reported in the table as companies define their own families of materials that they subsequently process

N° Interview	Core business/Main Operation	Origin of textile waste incoming [waste or by-product]*	Families of textile waste materials for recycling treated/purchased**	Characterization of waste - What information is available about the incoming material?	Laboratory Tests/Analyses on Incoming Material	Material Yield	Barriers to Acceptance
20	Shredding Carding Spinning	Post-Industrial Pre-Consumer	100% Cotton, pre-consumer waste	Yes, sample analysis performed for verification	Yes, fiber composition analysis	90-95% yield	Certification of origin, colorant verification, chemical testing
21	Shredding Carding	Post-Industrial Pre-Consumer Post-Consumer	60% Wool, 20% Cashmere, 10% Silk, 10% Cotton, pre-consumer waste	Trust in supplier, fiber composition	Planned sample-based tests	Cotton: 80%, Wool: 90%	No buttons, labels, metallic parts, finishes.
22	Weaving Kniting	Yarns produced from recycled natural raw materials, single-component	70% Cashmere, 10% Cotton, 20% Silk & Wool: 75% yarn and 25% deadstock (recovered wool fabrics used to create capsule collections)	95% accuracy in fiber composition	Yes, pollution, composition, pilling for cashmere, elasticity.	95%	Certification for yarns, full traceability for deadstock
23	Carding Spinning	Post-Industrial Pre-Consumer Post-Consumer	Premium fibers (Cashmere, Cotton, Aramidic) Goose feathers from down jackets:	Excellent, as materials come directly from customers	No lab tests conducted	85% yield	No restrictions, as materials come from customers
24	Spinning Shredding Chemical recycling	Post-Industrial Pre-Consumer	Primarily CO, PO/PES, WO, WO/Nylon, others	Depends on supplier, additional testing conducted	Yes, tests for amines, APEO, etc.	86% yield	Trust in supplier, internal certification ensures absence of restricted chemicals
25	Weaving Dyeing Finishing	Post-Industrial Pre-Consumer Post-Consumer	Recycled flame-retardant polyester recycled cotton recycled wool	100% accurate based on supplier trust	No lab tests, relies on OEKO-TEX certification	100% yield	Preference for OEKO-TEX certified yarns
26	Wool Tops Producer	Post-Industrial	N/A	Composition details, presence of chemicals	Sample testing for pesticides, Oeko-Tex, GOTS compliance	N/A	Current certification limitations prevent classification of some by-products
27	Sorting	Post-Industrial	80% wool, rest silk, cashmere, nylon	Wool fineness, composition. Chemical treatments.	No	0,98	No
28	Sorting	Post-Industrial	Mainly wool.	Composition and fineness. Chemical treatments.	No	0,98	No
29	Sorting & shredding	Post-Industrial	Wool and wool blends, cashmere and cashmere blends. Secondly cotton.	Composition (pure wool is more interesting) and fineness.	No	0,9	No
30	Sorting & shredding	Post-Industrial Pre-Consumer Post-Consumer	There are no prevalent fibers.	No limits	No	0,98	Not accepted. wet, smelly, resin, solvent, lurex or sequin material
31	Sorting & shredding	Post-Industrial	Almost entirely cotton.	Composition and color.	No	0,96	Selected suppliers. If materials can't be worked on, it won't be picked up.

Table 3: Data-driven synthesis of selected interviews based on comparable analytical categories.

Click on this link to download an extended and more detailed version of the table.

3.2 Textile Waste Collection and Management: Insights from Operators and Consortia

The textile recycling value chain starts well before the processing and transformation stages addressed by manufacturing companies, who represented the majority of the respondents we interviewed. As introduced with the Section 2, the critical early step is the collection sorting and management of textile waste, activities largely handled by specialized operators, municipalities and consortia. To gain a comprehensive understanding of the entire circular textile ecosystem in the Italian landscape, interviews were conducted with organizations directly involved in textile waste collection and handling in different Italian area. Their perspectives want to offer a valuable upstream complement to the voices of manufacturers and suppliers and are essential to understanding the broader systemic conditions influencing textile sustainability in the districts.

Currently, textile waste collection in Italy is undergoing a transitional phase marked by inconsistency and uncertainty. Although the obligation for separate textile collection officially came into effect on January 1, 2022, the actual implementation across municipalities remains uneven and often underdeveloped: on average, only about 3.5 kilograms per citizen are collected annually, revealing a gap between regulation and practice. Public administrations, often burdened with bureaucratic delays, have struggled to organize effective systems on the ground.

The textile collection chain is composed of a complex network of public and private stakeholders, each playing a specific role in ensuring that textiles waste are collected, handled and processed in accordance with regulatory frameworks and market dynamics.

Municipalities

Municipalities are the legal owners of household textile waste (post-consumer waste), once it is discarded. Under current legislation, they hold the responsibility for organizing separate collection systems within their jurisdictions. This responsibility can be exercised directly or through service contracts with other entities, as described in the following. In many cases, municipalities issue public tenders for the placement and management of textile collection containers (e.g. yellow bins), and they accredit third-party collectors who are authorized to operate within the local territory.

Third-Party Collection Operators

These include social cooperatives, private waste management companies, and other service providers authorized by municipalities to collect post-consumer textiles. Once they retrieve the material from collection points, they become its legal owners. Their revenue is derived from the resale of collected goods to sorting facilities, though in some cases they also pay a fee to municipalities for access to the material. Their role is not limited to logistics: many also perform quality checks or pre-sorting activities to improve downstream processing.

NGOs and Social Enterprises

Many textile collectors are non-profit organizations or social enterprises. Historically, they entered the sector to create employment opportunities, particularly for vulnerable populations, while providing a social reuse service. Although the sector has become more competitive and commercial, these actors continue to play a relevant role, especially in early-stage collection and community engagement

Producer Responsibility Organisations (PROs)

As introduced above, with the upcoming implementation of EPR schemes for textiles, a new category of actors will gain prominence: Producer Responsibility Organisations (PROs). These are collective entities created by producers and brands to fulfil their legal obligations in managing the end-of-life of textiles they place on the market. A PRO may take different legal forms—including a consortium—but not all consortia are PROs. Their mandate will be to coordinate and finance collection, sorting, and recycling logistics on behalf of producers. They will also define standards, organize tenders, accredit facilities, and ensure that legal and environmental obligations are met.

Producers and Brands

Beyond financing the system via eco-contributions, producers and brands may also engage in voluntary take-back schemes. In addition, their role increasingly extends upstream, as product design decisions - such as fiber composition or ease of disassembly - directly influence recyclability and end-of-life management.

At present, for example in Tuscany, the post-consumer collection is largely carried out through yellow roadside containers managed by third-party entities accredited by the municipalities. These organizations assume the ownership of the materials once collected, after which they resell the items to sorting/shredding operators. In return, the collectors pay a fee to the municipalities or to local entities, which oversees parts of the process. This system, however, creates several complications. The ownership transfer model limits control over the quality and traceability of the collected materials. Furthermore, with no uniform regulation or centralized planning in place, local practices vary greatly, undermining overall efficiency. To address specific needs such as seasonal wardrobe changes, in Tuscany, some pilot projects for on-demand collection were started. This service model, designed to be replicated across other waste types such as used cooking oil, relies on digital applications for user engagement and logistics coordination. Its success depends largely on speed and responsiveness, since textile items degrade rapidly when exposed to environmental conditions such as humidity or rain. Rapid pickup becomes crucial to preserve the integrity and potential reuse or recycling value of the collected garments.

In the post-industrial and pre-consumer domains, waste primarily originates from production defects, surplus inventory and off-cuts. This type of waste is generally cleaner, more homogeneous and therefore more manageable. However, current practices reveal several operational limitations. In many cases, spinning mills, weaving mill, and other production-phase companies directly contact the waste collector of their choice - often selected based on collection cost considerations - to arrange for the pickup of textile scraps. These scraps are usually handed over without any internal sorting, as no legal requirement mandates separation by fiber type, color, or lot, and the effort involved would be excessive given the high heterogeneity (multifiber compositions, small batch sizes, color variations).

Companies that dispose of their waste are nonetheless informed about the subsequent destination of the materials through waste return codes, which indicate whether a portion of the discarded material is recycled.

Artisans and small businesses, on the other hand, often express concern about the potential costs associated with joining consortia or associations. The fear of additional financial burdens acts as a barrier to participation in organized waste management systems, potentially leaving this segment underserved within the emerging EPR framework.

The interviewed Consortia, which operate across several waste streams including textiles, also manage this segment through a network of many centers. These centers focus on collection and storage and do not undertake recycling operations directly. Instead, they collaborate with external recycling partners. In any case, the collected materials must align with existing downstream outlets; if no appropriate solution exists for a given type of textile, that item is excluded from the collection.

The prevailing logic remains grounded in the waste hierarchy, which prioritizes reuse over recycling and disposal. Yet, this ideal faces several operational barriers. In many cases, less than 50% of the collected textile material is reusable, and only about 30–35% qualifies as first- or second-choice quality. The remainder, often composed of low-grade mixed fibers, faces limited recycling options. Current reuse-driven systems do not adequately address this volume of non-reusable material, which often ends up downcycled into low-value products like industrial rags or insulation.

Adding to the complexity is the economic side of collection. Historically, collectors could generate profits through the resale of quality garments, even paying municipalities for the right to collect. Today, however, declining material quality - due to fast fashion and platforms like Vinted - and rising operational costs have flipped the equation. Expenses for transport, storage, personnel, and permits often outweigh the returns from material sales. Moreover, geographic variability impacts cost: collections in mountainous or rural regions are significantly more expensive than those in urban settings.

Export practices further complicate the situation. While legal and ethical exports of reusable garments to low-income countries help extend the lifecycle of clothing, unethical practices also persist. In these cases, unsellable textile waste is fraudulently labeled as reusable and exported to avoid disposal costs. Once abroad, only a small fraction is salvaged, while the rest is illegally dumped, causing environmental harm and distorting international markets. Associations have recently begun working with customs authorities to train officials to better identify and intercept such shipments.

Looking ahead, expectations for the sector are shaped by both regulatory shifts and structural necessities. The implementation of a clear and enforceable EPR framework is seen as critical. Such a framework would place the financial and logistical responsibility for textile waste management on producers, ideally incentivizing upstream improvements in product design and material selection. The EPR model may resemble the one used for WEEE (electronic waste), in which collection centers are accredited and managed under coordinated tenders, and consortia have the freedom to partner based on commercial logic. Italian Consortia are already preparing for this new phase.

By 2030, manufacturers will be required to include a set percentage of recycled fiber in their products. This upcoming regulation places increasing pressure on the development of recycling infrastructure, particularly for complex and blended materials that cannot be processed through traditional mechanical methods. While mechanical recycling still works for recycled wool, it is well known that the majority of textiles currently on the market are of lower quality and composed of blended fibers. These modern textiles, often made from mixed materials such as polyester-cotton or elastane blends, require advanced recycling processes - also chemical - that ask for technologies that are still expensive and not yet fully developed. For example at now, virgin polyester remains cheaper than its recycled equivalent, a gap that can only be bridged through subsidies or eco-contributions. Funding must be directed toward solving the challenges of non-reusable materials - developing new recycling technologies, establishing end-markets, and supporting unprofitable but necessary activities.

Finally, there is a strong call to relocalize the textile waste loop within Europe. Current practices -whereby waste is exported to countries like India for disassembly before being reimported into Europe - are economically viable but environmentally unsustainable. With the proper legislative framework and financial support in place, future investments should aim to close the loop domestically, ensuring that textile waste becomes not a burden, but a resource for a truly circular economy.

3.3 The role of Suppliers of Textile waste materials for recycling in the Circular Textile Economy

The suppliers of textile waste material for recycling, in particular for feeding the processes that transforms discarded textiles or production waste into new products, are an essential component of the entire value chain.

There are different categories of suppliers, each operating in different ways within their respective markets of origin and/or material destination.

The textile districts of Prato and Biella are characterized by a complex and diverse network of suppliers that provide post-industrial, pre-consumer and post-consumer textile materials: generally, suppliers are selected based on their ability to provide textile materials for the transformation processes with a predominant wool composition (>80%) and/or fibers of animal origin (e.g. cashmere).

Naturally, these central fibers are combined by a wide range of others, varying from cotton to an array of synthetic fibers currently used in our garments, such as polyester, nylon, other fibres (OF).

Waste materials are rarely composed of a single type of fiber: in the vast majority of cases, they are multicolored and multi-compositional, making their separation into consistent "families" particularly challenging, especially given the relatively small batch sizes typical of many recycling operations.

In contrast, mono-material textiles are becoming increasingly valuable within the recycling ecosystem. Their uniform composition significantly simplifies sorting and enables more efficient, higher-quality recycling processes. This shift aligns closely with the principles outlined in textile eco-design guidelines, which emphasize the importance of designing products with end-of-life in mind. By promoting the use of single-fiber materials and reducing blends and complex finishes, these guidelines support greater recyclability and a more streamlined circular flow of materials. As such, mono-materials are now seen not only as technically advantageous but also strategically essential for building a more sustainable textile economy.

Suppliers of textile waste materials in the Prato district vary widely in geographical location (chapter 3.3.1) and material type supplied.

Post Industrial waste - Suppliers: Primarily include textile manufacturing offcuts and trimmings from production. These are spinning mills, weaving mills, or garment manufacturers that daily collect textile waste during the process. The waste origins from processing scraps/leftovers, cutting and fabric head. These are normal waste from the textile processes that would become waste for landfill if they will not collect for the regeneration process.

In the textile district of Prato there is a well-organized system for the post industrial waste: producers of carded yarns/fabrics and companies that create recycled textile-based products not destined to the fashion industry, have long established partnerships with companies that process fabrics and yarns, whose waste is of high interest within the recycling system. This is due to the quality, consistency in composition and regular quantity of the waste. Often, third-party companies that process textile materials become suppliers of recycled textile materials for their own clients.

In many cases, the suppliers of high-end textile manufacturing companies and brands, generating waste from fabrics and fibers during their production processes, become also their customers. This waste is recovered to create new yarns, which are often returned to the same suppliers in the form of finished products. For example, the waste collected from the combing phase of these brands retains high performance because originates from a high-end textile material, even though it was originally discarded.

In Biella area there are commercial agreements rather than partnerships between those who produce post-industrial waste and those who recover it to reintroduce it into the recycled supply chain, whether it involves fibre-to-fibre processes or other destinations.

The interviewed companies in Prato primarily source their post-industrial waste materials from Italian companies, particularly in the districts Biella, where the largest combed wool mills are located today.

If these waste materials were not recovered, as the Prato and Biella tradition has taught us for centuries, they would need to be disposed of as waste, thus losing significant value and potential.

Pre consumer waste - suppliers: These actors handle textile products - often fully finished garments or semi-finished items - that never reach the market due to overproduction, quality issues, design flaws, or changes in fashion trends. Unlike post-consumer waste, which comes from used clothing, pre-consumer waste is typically cleaner, more homogeneous and often in better condition, making it highly valuable in both reuse and recycling processes, or other 5R pathways.

There is significant untapped potential in this segment for reuse, as many of these garments are unused and retain full functional value. When reuse (or repair) is not possible, the items can enter recycling streams, but only after undergoing proper selection and dismantling. This step is crucial and follow similar critical issues of post-consumer waste, as garments often consist of mixed materials (e.g. cotton-polyester blends), include accessories such as buttons, zippers, and labels or feature treatments (like coatings or finishes) that complicate recycling. In few words, it's generated before the product reaches the consumer, yet after significant value - in terms of materials, labor, and energy - has already been added.

Post consumer waste - suppliers: Focus on garments and textiles collected after consumer use, requiring additional processing such as sorting and cleaning.

Traders (Intermediaries and Textile Brokers) and Textile Recycling Consortia and Cooperatives represent transversal categories of suppliers that operate across the post-industrial, pre-consumer and post-consumer waste streams.

These actors play a crucial role in bridging the gap between waste generators and recycling-oriented manufacturers.

Traders (Intermediaries and Textile Brokers): Traders purchase textile waste materials for recycling from collection, selection, and recycling companies and then resell them to other manufacturing industries that produce new recycled fabrics or finished products. The traders supplying the interviewed companies mostly operate on an international scale and provide access to waste materials from various sources.

Textile Recycling Consortia and Cooperatives. These are groups of companies and cooperatives that work together to coordinate the collection, recycling, and distribution of textile fibers (see also section 4.2). These consortia may operate on a regional or national level and provide access to recycled textile materials to various industries, both pre-consumer and post-consumer.

3.3.1 Origin Of Suppliers: Geographical Distribution

Most of post-industrial and pre-consumer waste is sourced locally within Italy and neighboring European countries. The interviewed companies primarily rely on Italian companies for post-industrial waste materials, specifically from the Prato district and Biella district, where the largest worsted wool mills are currently located. However, they also work with waste materials purchased from suppliers and/or intermediates situated in different parts of the world.

In particular, the traders operate in American regions, some European areas, India, Pakistan, Japan, Australia and New Zealand. The latter are the main countries to which carded wool companies turn, due to the scarcity of both raw materials and secondary materials in Europe.

The United States represents one of the main suppliers. American suppliers and/or those managing textile waste from the U.S. are an important resource for companies involved in the production of recycled textile products. This is because the typical American consumer culture leads to a significant quantity of post-consumer textile materials. Americans are used to purchase large quantities of products and have a high consumption cycle, where rapid adoption of trends and fashion promotes frequent wardrobe changes. This means that many garments, often in good condition or of high quality, quickly enter recycling channels. Frequently, these garments are branded: the United States is a major market for high-end brands and products, which often include garments made of wool and other high-quality materials realized with natural fibres. Even when these products are discarded, they are often in a condition suitable for recycling into high-quality yarns or fabrics. Furthermore, due to the diversity of consumers and the vastness of the market, America offers a wide variety of textiles and fibers, ensuring a good supply of wool of different qualities, styles, and origins, thus increasing the chances of obtaining high-quality recycled material. For example, post-consumer cashmere from America is an excellent resource for regeneration.

India and Pakistan are key countries in the textile recycling sector, even though textile materials do not originate from these regions. They are of interest because they have well-organized operations for the "sorting" phase of recycling -predominantly post-consumer materials. From India and Pakistan, sorted bales of textile waste materials, often categorized by color and sometimes by composition, are shipped to textile districts, mostly through intermediaries. This practice has been in place for several decades, and although the environmental impact of material logistics has increased exponentially, the choice to source from these countries is driven by the cost-effectiveness of labor in the sorting process and by the difficulty of finding diligent and consistent personnel in Europe, particularly within the districts, to handle material sorting.

There are also significant collectors of textile waste materials for recycling in Romania.

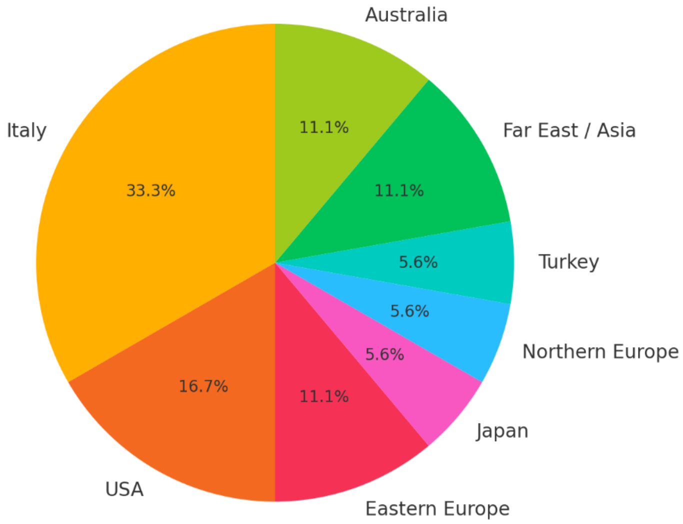


Figure 4: Geographical areas mentioned in interviews, represented as percentages of suppliers providing textile waste materials for recycling[2]

[2] note that these data are not precise measurements but are based on the number of times each geographic area was mentioned in the interviews as the origin of recycled materials. The proportions reflect the frequency of mentions relative to the total number of interviews. It is important to emphasize that this analysis is qualitative, not quantitative.

3.3.2 Quality and accuracy of the supplies

The quality of the textile waste material for recycling used as input in the regenerated processes is evaluated with extreme care, as it directly impacts the production efficiency and the quality of the final product containing recycled material. The selection of suppliers and materials is based on a **combination of criteria** dictated by the experience of who works in carded wool from generation to generation and by the intended use of the final product: the goal is to ensure that the material is **suitable for its final application.** The quality of the waste material is not only assessed in terms of purity or absence of contamination, but also based on the expected final output and the specific requirements it entails. For instance, the shredded textile material entering the process can vary in size, from smaller to larger pieces, but as long as it meets the standards of the final product, it is considered acceptable. It should be noted that sometimes the delivered material contains gross contaminants, such as coffee cups, stirrers, various waste, or other refuse.

The quality of the material selected at purchase certainly depending on whether the recycled product is intended for the fashion industry (**value chain fiber-to-fiber F2F**) or for recycled textile-based products used in **other sectors** (e.g. construction - **value chain fiber-to-other applications**).

If the textile material is destined to re-enter the fashion supply chain, yarn and fabric manufacturers are particularly committed on its **composition** and **homogeneity**.

One of the most significant challenges in the textile recycling industry is the complexity of ensuring - at each given quantity of textile waste material for recycling entering the process - a consistent composition because:

- If the material is post-industrial and pre-consumer, in most cases the waste is never mono-fiber, but rather multicolored and multi-composed, both due to the source of the material being processed (e.g., patterned yarn/fabric) and because separating by composition type during collection is always very complex, primarily due to the very small average batch sizes (at now the maximum batch sizes currently range between 1,000 and 2,000 kg, of which the spinning waste represents an average of 5%).
- If the material is pre and post-consumer, there is significant fiber and material diversity as it comes from various sources and is often already composed of a fiber blend. The criticality of the sorting phase is central here. Additionally, pre and post-consumer products are often still "assembled," meaning they still have buttons, zippers, labels, or other accessory elements (elastics, plastics, metals). Post-consumer textiles can vary in wear, strength, and quality. Some garments may have been washed and worn many times, reducing fiber strength, while others may have been used less frequently and retain higher quality. Moreover, in the post-consumer world, unlike pre-consumer, it is difficult to trace the history of individual textiles. This means that it is often unclear which fibers are present, where they come from, or how they were treated before recycling. This can compromise the ability to ensure a homogeneous and high-quality result.

In general, the presence of dye residues, chemical finishes and dirt can also complicate the recycling process, making it harder to achieve uniform material composition.

Another issue concerns the categorization of the material itself. For example, when the material contains a combination of fibers, such as wool and polyester (80%-20%) or wool and nylon (70%-30%), it can be processed quite easily. However, more complex blends, such as wool and viscose or wool and cotton, present greater technical difficulties.

In F2F recycling, the quality of textile waste is primarily assessed based on three key physical characteristics of the fibers: **length, uniformity and fineness**. Fiber length is the most critical factor, as longer fibers offer better cohesion and strength during carding and spinning processes, leading to more durable and higher-quality yarns. Next in importance is uniformity, which refers to the consistency of the fiber's length and fineness within a batch; uniform fibers help ensure smooth processing and even yarn performance.

Fineness, typically measured in microns (μm) in wool industry and in micronaire in cotton industry, describes the thickness of individual fibers. Finer fibers produce smoother, softer and higher-quality yarns and are therefore more suitable for premium applications such as luxury apparel or high-end knitwear. In this context, textile waste made of finer fibers is often referred to as "**fine" material**, while less fine fibers (thicker, less delicate) are categorized as "ordinary". "**Ordinary**" fibers are generally used for more robust or industrial applications, where finesse and softness are not critical requirements.

A further, more indirect indicator is the **yarn count (or title)** of the original textile material. This parameter describes the ratio of length to weight in a yarn and it helps infer the fiber's original quality. A high yarn count (fine yarns, such as Ne 40) typically implies the use of finer, higher-grade fibers, while a lower count (coarser yarns) suggests thicker, more robust fibers.

Evaluating these characteristics in combination allows recyclers to correctly sort and match textile waste to its most appropriate recycling and end-use pathways, optimizing both material recovery and product quality.

Particular attention is also given to the presence of vegetable fibers in the bales of material, as they can reduce the final usable weight and thus negatively affect profit margins.

Another determining factor in the selection is the **consistency of supply**. Suppliers must guarantee continuous and consistent delivery to ensure a regular production flow. Suppliers offering occasional waste or unable to guarantee substantial quantities are not accepted and could be delivered to disposal.

Both pre-consumer and post-consumer recycled textile materials arrive at the client companies in large trucks carrying 20 to 25 tons of material. The loads vary in composition and color: the companies receiving the material usually perform a finer sorting process to then store the bales of material, allowing for quicker selection when designing the new recycled products.

Often, the material purchased goes through a "**Receiving phase**" before being delivered, during which the potential buyer visits the sales warehouse or receives a series of samples to visually and manually evaluate the quality of the material itself.

3.3.2.1 The Importance of color homogeneity in incoming textile recycled materials

Color homogeneity plays a critical role in textile recycling, particularly when dealing with post-consumer materials. Homogeneous colors reduce the need for additional dyeing processes, which are resource-intensive and can negate some of the environmental benefits of recycling.

For instance:

- Reduction of resource use: materials with uniform colors bypass the need for extensive re-dyeing, conserving water, energy, and chemicals.
- Enhancement of recyclability: uniformly colored batches simplify sorting and processing, allowing for more efficient production of consistent, high-quality recycled outputs.
- Market perception: recycled materials with stable and predictable color properties are more easily accepted by industries such as fashion, where aesthetics play a critical role.

Case Study: managing Color Homogeneity in Yarn production

A Prato-based spinning mill specializing in recycled yarn production, processing 85% post-consumer waste and 15% pre-consumer waste (Interview 8). The company faced significant challenges in maintaining consistent color homogeneity due to the diverse origins of the post-consumer materials. Each batch of recycled material required specific adjustments to achieve the desired color consistency.

The process begins with the client specifying the desired color and its exact shade. For instance, the company offers 43 shades of black alone, which must be precisely matched to client expectations. Incoming materials stored are selected and blended to create a preliminary batch, that is manually inspected to identify color matches, discrepancies and sorted accordingly. This blend is tested multiple times using a mini-carding machine. The mini-carding machine allows technicians to visually evaluate how closely the blended material matches the desired color. Adjustments are made iteratively until the color meets client expectations. In cases where color discrepancies cannot be resolved through blending alone, virgin fibers are added to stabilize the shades. The approach minimizes waste in the production phase and reduces the environmental footprint by limiting additional dyeing and chemical use.

Key Points: Quality and Accuracy of Supplies

- Material Homogeneity: Significant variability exists between pre-consumer and post-consumer waste. Pre-consumer waste often arrives in more predictable conditions but may still include contaminants like dust, large pieces, or mixed materials.

- Post-consumer waste is highly heterogeneous, with frequent issues related to embedded contaminants such as labels, stitching, or mixed fibers.

- Certification and Traceability: While some waste materials arrive with certifications like REACH or OEKO-TEX®, detailed traceability is often limited, leaving gaps in understanding the origin and previous processing of the supplies.

- Testing and Verification: Companies prioritize testing for contaminants and chemical pollutants, such as APEOs, to ensure compliance with safety standards and usability requirements. Suppliers may provide limited technical data, requiring additional testing by the receiving companies.

Figure xxx - Bales of post-consumer textile fibers, sorted by color, await blending and testing to meet precise client shade specifications

3.4 The Families of Textile waste for recycling material

This chapter delves into a pivotal aspect of textile recycling at Prato and Biella: **the categorization of textile waste for recycling,** which in this report and our current studies we refer to as **“families”**. Through in-depth interviews with key stakeholders in the recycling process, we aim to bring clarity to the materials that are – currently, with the avaiable knowledge and skills - both preferred and viable for recycling. By doing so, we seek to establish a framework that can not only scale within Prato and Biella but also serve as a transferable model for other materials and industries.

In this effort, we attempt to assign “names and identities” to the most used textile waste materials in the districts. These are often blended compositions that industry professionals instinctively recognize and process out of necessity, using techniques and knowledge accumulated over generations. This expertise, however, is at risk of becoming lost, as it is rooted in tacit practices rather than standardized laboratory methods - like “biting into a fiber to discern its wool content.”

Formalizing this knowledge is essential to preserve and leverage it for future advancements.

Understanding material families enables us to link the textile waste material for recycling being purchased and processed to their possible applications. Such an approach could lay the groundwork for creating a recyclability index as explored in Section 5. Moreover, this “catalog” of textile families offers designers - both in fashion and beyond - an invaluable resource to better understand and, consequently, incorporate recycled materials into their work. By capitalizing on this knowledge, the industry can lower barriers to entry for circular textile design and broaden its appeal. At this stage, information and educational efforts take on great importance.

Unconsciously, these material families act as the primary codes in managing recycling processes. For instance, certifications like GRS (Global Recycled Standard) often rely on or could further refine their material balance sheets based on these classifications.

However, our interviews reveal a surprising insight: many companies, especially those operating as third-party company involved in processing materials to create intermediate products or treatments for the final textile product, lack a comprehensive understanding of the material families they handle. Despite this gap, we also discovered that material families don’t always critically influence or disrupt processing stages, as one might assume. Nonetheless, we need to render these insights systematic - more logical and scientific - so they become accessible to a broader audience. By doing so, we can attract new professionals and inspire innovation within the textile circular economy.

In conclusion, this chapter presents an opportunity to bridge traditional expertise with modern systems thinking. By organizing and cataloging textile waste material families, we can transform the inherent knowledge of Prato’s and Biella’s textile recycling community into a scalable model that benefits global circular economy efforts.

“When can we truly say we have a family of textile waste for recycling?” This question is critical because the way we define and organize these families influences the application where they are used and the key processes that will be used for using the material in the final product, as in a perfect circular approach.

“A family of textile waste for recycling can be considered established when a group of materials shares consistent and identifiable characteristics - whether related to fiber composition, color, or other end-use requirements - allowing for effective classification and processing that will support a well-defined recycling pathway.”

A crucial step in achieving the families of textile waste for recycling is the **sorting phase**, a fundamental component of the recycling value chain for any material.

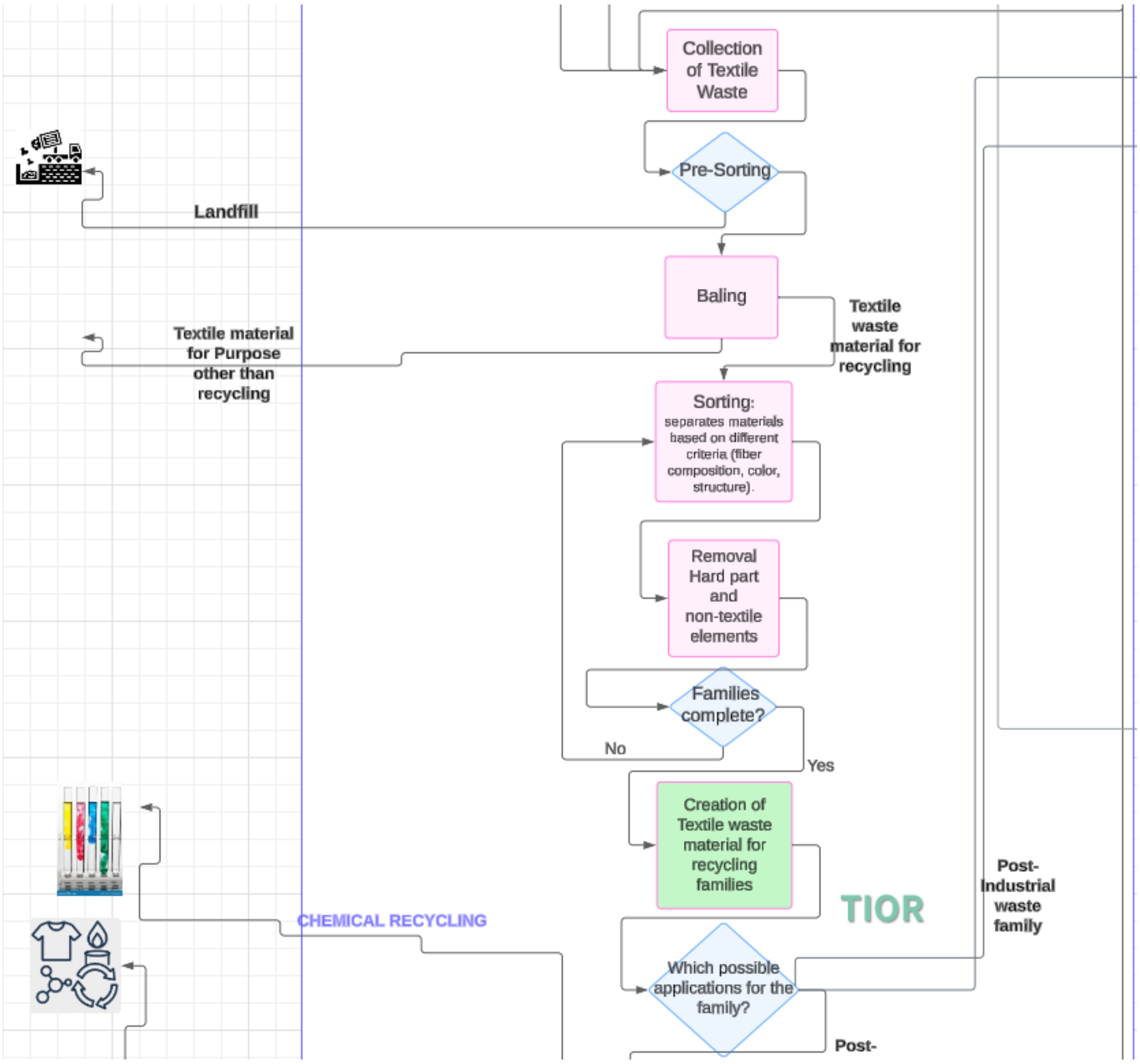


Figure 5: Extract from the value chain mapping in Chapter 2

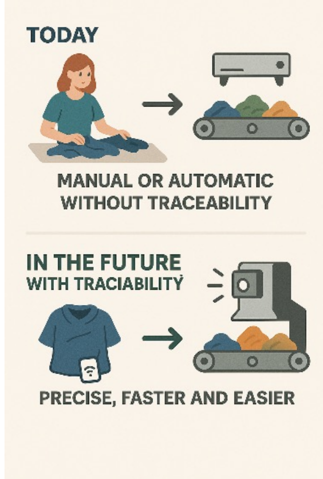
As introduced in chapter 2, textile waste is first directed - through a pre-sorting phase - towards one of the five R pathways or to the landfill. Once the flow follows the path of recycling, sorting becomes a pivotal operation, enabling the transformation of incoming, heterogeneous textile waste into coherent material families suitable for recycling processes.

In our representation **"Sorting is what enables the creation of distinct families of textile waste materials for recycling, tailored to different applications"**

By grouping materials based on the desired end use, this phase ensures that the sorted materials can be effectively directed to the appropriate recycling pre-treatments and treatments, ultimately transforming them into products that meet specific design and performance requirements.

In the textile recycling industry, the sorting phase is pivotal for transforming mixed and disorganized textile waste, already selected for recycling, into categorized groups of textile materials. These categories are defined by specific conditions that facilitate the appropriate processing and end-use application of the materials. Traditionally, this task has been performed by skilled manual sorters, known as "cernitori" in Prato and Biella, who classify textiles based on various criteria. These experts distinguish textiles by fiber composition, color, structure, and type of textile piece (e.g., T-shirts, pants, machine scraps). Their expertise allows them to handle a wide range of conditions, ensuring that materials are appropriately categorized for subsequent recycling processes.

Replicating the nuanced judgment of manual sorters in automated systems presents significant challenges. Engineers and technicians are actively developing automated sorting technologies to emulate these manual sorting capabilities. Modern automated systems employ advanced techniques such as Near-Infrared (NIR) spectroscopy, hyperspectral imaging, and artificial intelligence to identify and separate textiles based on fiber composition, color, and, to some extent, structure. For instance, Daedalus, the semi-automated sorting system developed by Next Technology Tecnotessile, applies a combination of hyperspectral imaging and NIR spectroscopy to classify textiles according to fiber composition, fabric structure, and color. The system can process more than 60 garments per minute through simultaneous analysis, once a training phase has been completed to calibrate the recognition algorithm with a representative dataset.



Despite these technological advancements, automated and semi-automated systems still face challenges in replicating the nuanced expertise of manual sorters, particularly in handling highly heterogeneous textile forms. Nevertheless, such innovations are considered a crucial step in improving efficiency and productivity in textile recycling. For further details on prototypes and new developments in the sorting phase, see the recent work of Next Technology Tecnotessile (https://www.tecnotex.it/macchina-semiautomatica-per-la-selezione-e-la-cernita-di-materiali-tessili/indumenti-post-consumo).Below, by the figure xxxx, we introduce some key actual criteria adopted for the creation of material families in relation to the objective application, as we mentioned before.

While multiple methodologies exist to define and organize these families, this chapter adopts a fiber composition-based classification. This choice is guided not only by its relevance to the recycling process but also because it emerged as the dominant criterion during interviews with the key actors. When discussing material families or bales of incoming or purchased materials, they primarily differentiate them by fiber composition. Some actors further specify categories such as 'fine' or 'ordinary,' which, as we will explore in Chapter 5, refer to the fiber fineness.

Furthermore, this approach aligns with the well-established categories used for virgin fibers (natural fibers and man-made fibers) offering a linear framework for comparison, reflection, and innovation with recycled textile materials. By leveraging this structure, we aim to connect recycled and virgin materials, enabling clearer terms for evaluating gaps, opportunities, and innovations across fiber systems..

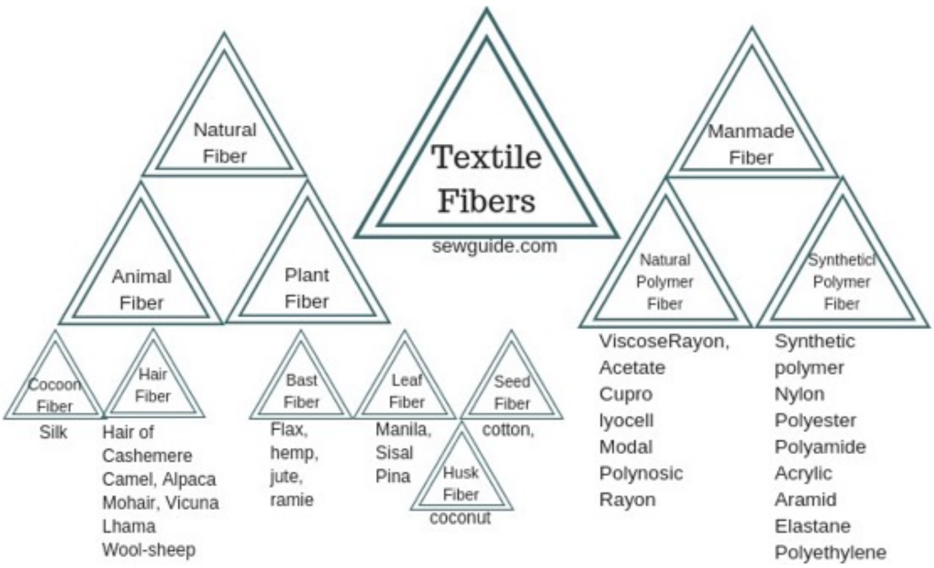


Figure 6: Representation of different types of textile fibers, both natural as well as man-made fibers (sewguide)

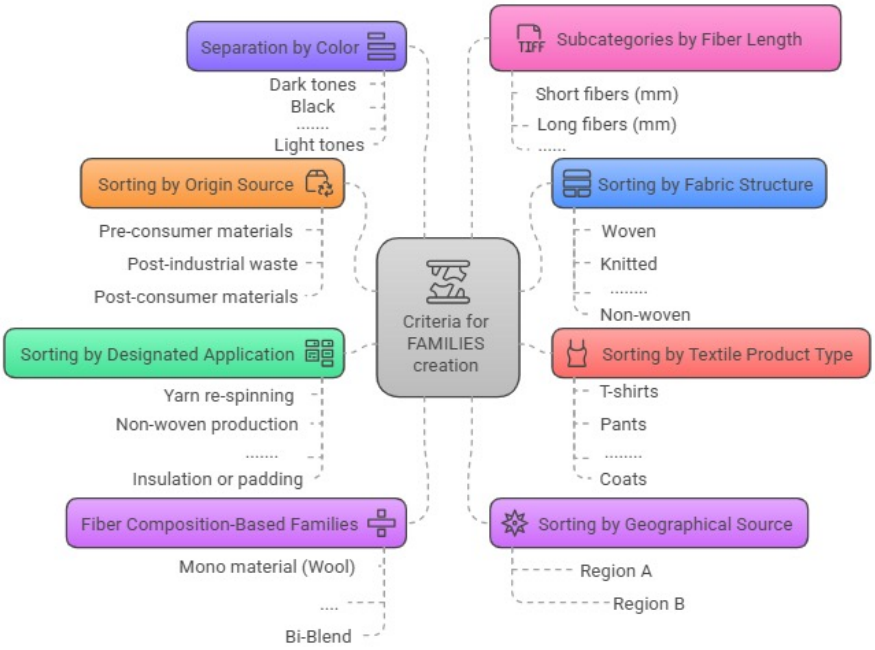


Figure 7: Map of Sorting Criteria for Textile waste material families

Sorting by origin source:

- **Pre-consumer materials** includes leftover materials from the production process, such as cutting scraps and unused fabric rolls
- **Post-industrial:** Waste generated during the manufacturing process, including fabric remnants and defective materials.
- **Post-consumer materials**: used garments addressed to recycling processes

Sorting by Geographical source:

Materials are categorized based on their region of origin, as different geographical sources may impact the quality and type of fibers, contamination levels, and processing requirements.

Example: In the interview 2, the company sources most of its recycled cashmere from the United States, where a surprisingly high volume of usable cashmere is discarded. This makes geographical origin a key factor — not just in fiber quality, but also in volume and availability.

Separation by Color:

Homogeneous color families are created to avoid additional dyeing. For example, dark shades like black or navy are grouped together, while lighter shades form separate families.

Example: In the interview n.2, the company reported that the recycled cashmere received arrives pre-sorted by color in small bags within large containers. Sorting by color helps them avoid re-dyeing and preserve fiber quality

Sorting by Fabric Structure:

Materials are classified based on their structural characteristics, such as woven, knitted, or non-woven textiles, which influence their potential for recycling and end-use applications.

Example: In the interview 3, the company stated that the most of the incoming materials are knitted fabrics (90%), with only a small share (10%) being woven. This affects both the mechanical recycling process and the final yarn quality. The structural distinction is crucial for processing: knitted fabrics are generally easier to mechanically shred, especially with dry methods, which are less resource-intensive.

Sorting by Textile Product Type:
Materials are distinguished based on the type of product they originate from, such as T-shirts, pants, dresses, or machine cutting scraps, to optimize downstream processing such as …

Example: In the interview 6, the company receives pre-sorted garments and mechanically shreds them. Each garment type has distinct structural characteristics (e.g. knitted vs. woven), accessories (zippers, buttons, linings), and fiber compositions, all of which affect how the material can be mechanically processed. For instance, T-shirts are typically lightweight and easy to shred, while coats may require additional steps to remove padding or non-textile components.

Sorting by Designated Applications:
Material families are defined based on their intended end use, such as re-spun yarns, non-woven products, insulation, or cross-sectoral applications like construction materials.

Example: In the interview n.1, the company stated that most of their recycled material ends up in mattress production or automotive insulation, where mechanical properties, not aesthetics, define value.

Subcategories by Fiber Length:
Short fibers (<15-20mm) are often classified as low-value and used in non-textile applications, while longer fibers (>50mm) are reserved for re-spinning.

Example: In the interview 9, the company distinguishes between short fibers (under 15–20 mm), which fall by gravity during carding and are considered unusable for spinning, and longer fibers, which are kept for yarn production. This physical property alone determines whether the material is recycled into high-value yarns or low-value byproducts.

Fiber Composition-Based Families
Grouping materials according to fiber type (e.g., wool, cotton, polyester) and/or blend proportions, which is critical for ensuring proper downstream processing and product quality.

Example: In the interview 9, the company reported that recyclability was affected by fiber blends: while wool-polyester or wool-nylon compositions were acceptable, blends like wool-viscose were more complex to process.

3.4.1 Families of textile waste for recycling materials based on Fiber composition

As mentioned above, the textile material families based on fiber composition are groupings of materials that categorize textile material **according to fiber type and blend proportions**. These families align with the structure of virgin fiber classifications to ensure consistency and comparability. By organizing materials in this way, it becomes easier to understand their properties, potential applications, and limitations within various production and recycling processes.

In general, the macro-categorization for creating the Fiber Composition-Based Families for textile waste material for recycling could be:

Family Type	Definition	Typical Composition	Features
1. Mono-Fiber Families	Made of a single fiber type (≥ 95%)	100% Cotton, 100% Wool, 100% Cashmere, 100% Polyester	Easy recycling, homogeneous performance, eco-friendly in circular systems
2. Bi-fiber blend families	Blends of two fibers (natural/natural, natural/synthetic, or synthetic/synthetic). Include combinations of natural and synthetic fibers, such as wool-polyester or cotton-viscose blends	Wool – Polyester, Cotton-Polyester, Cotton-Linen, Nylon-Spandex	Enhanced comfort, performance, cost-efficiency
3. Multi-fiber blend Families	Contains three or more different fiber types, like wool-acrylic-polyester blends.	Cotton-Polyester-Elastane, Wool-Nylon-Acrylic	Used for sportswear, stretch garments, fashion. Offer multiple functional properties
4. Specialized Fiber Families	Focused on unique applications, including fire-retardant materials, high-durability blends for industrial use, or eco-friendly combinations like recycled PET with organic fibers		
4a. Engineered / Functional Families	Designed for technical functions or performance needs	Aramid blends, Kevlar composites, Tencel-Coolmax	Fire resistance, moisture management, medical use, industrial durability
4b. Eco-Designed / Recycled Families	Made with recycled or low-impact fibers; often certified	Recycled PET + Organic Cotton, Hemp + Lyocell	Sustainable design, low-impact production, recyclable or biodegradable options

Table 4: Proposal of a macro-categorization framework for textile waste, grouping materials into fiber composition–based families

3.4.1.1 Families of textile waste material for recycling based on Fiber composition tracked on the interviews

The interviews conducted with key companies and stakeholders in the Prato and Biella district revealed some textile waste material families that play a crucial role in the local recycling ecosystem. These families, primarily defined from the interviewees by fiber composition, followed by parameters such as color, waste origin (post-industrial or post-consumer) and geographical origin, highlight the central role of fiber-based categorization in the industry. The interviews confirmed that categorizing textile waste materials by fiber composition is one of the most commonly used methods and the main approach for ordering, acquiring and transforming textile waste materials.

1. Mono-Material Fiber Families	Wool
	Cotton
	Cashmere
	Alpaca
	Mohair
	Polyester
	Polyamide
2.Blended Fiber Families	Wool-Polyester (80-20)
	Wool-Nylon (70-30)
	Wool-Viscose
	Wool-Cotton
	Polyester-Cotton
	Wool – OF (85-15)
	Cotton-Viscose
	Eco-Cashmere (85%) blended with Wool (15%)
3. Multi-Component Fiber Families	Cashmere-Silk-Cotton
	Wool, Acrylic, OF (30-30-30)
	Blends with Aramidic and Technical Fibers
	Polyester and Natural Fiber Blends
4. Specialized Fiber Families	Aramidic Fiber Blends
	Undefined material
	Blends with Aramidic and Technical Fibers
	Polyamide

Table 5: Typologies of incoming textile waste families identified through interviews, alongside the compositions considered most valuable for recycling pathways in the Prato and Biella districts.

[3]During the interviews and the analysis of recycled textile material flows, an important category emerged that cannot be overlooked: the "undefined" or "mixed" materials family (as named "Rossino"). These materials, which do not fit into a specific classification based on composition or origin, represent a significant resource for applications where the quality and specificity of the inputs are not critical, as long as minimum legal safety standards are met. This family includes a wide range of heterogeneous materials derived from post-industrial waste, post-consumer sources. These can encompass combinations of synthetic and natural fibers, production leftovers, colours and other untracked inputs. Their main application lies in sectors where the functionality of the material outweighs the need for precise fiber characteristics.

However, identifying which material flows are most or least used, remains a complex task. Among the 36 interviews conducted, there tends to be a near 1:1 ratio between different material families and the preferences expressed by stakeholders. This could indicate two possible scenarios: either the sample size analyzed is too small to define clear trends, or the sample is sufficiently representative of the sector, suggesting that these material families are precisely where we need to start to define production segments. Additionally, this observation could reflect the inherent diversity and adaptability of Made in Italy, where each actor seeks to personalize and differentiate their production by carefully selecting unique materials - even when dealing with recycled inputs. This variety highlights the creativity and craftsmanship embedded in the Italian textile industry. In any case, to provide a clearer picture, we present below several data-driven analyses derived from the synthesis of the interviews for the families fields, as well as being presented and listed in the column “Families of incoming textile waste material for recycling” of Table XXX. The purpose of these analyses is to inform the growth of priority “transformation of textile waste” segments, acknowledging at the same time the heterogeneous nature of the materials in use.

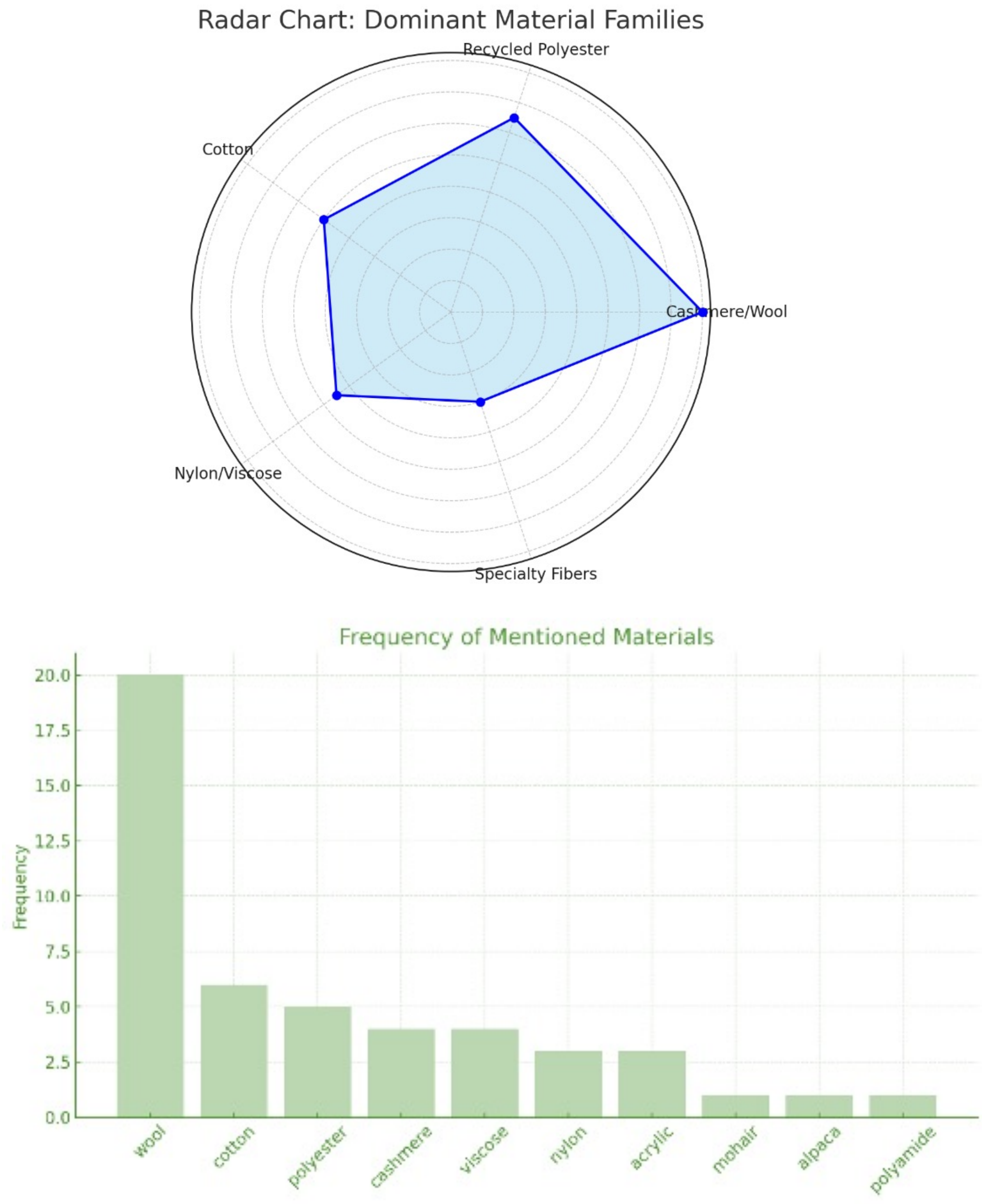


Figure 8: Statistical analysis of how often textile materials for recycling were mentioned during interviews, as an indicator of interest or use - with a focus on the Prato and Biella districts

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This family includes a wide range of heterogeneous materials derived from post-industrial waste, post-consumer, or pre-consumer sources. These can encompass combinations of synthetic and natural fibers, production leftovers, colours and other untracked inputs. Their main application lies in sectors where the functionality of the material outweighs the need for precise fiber characteristics.

3.5 Flows and Quantity of textile waste material for recycling. The Textile material yield as proximity data

Market demand for textile waste material for recycling has fallen sharply in recent decades. We can suppose that this reduction is also due to the insufficient quality of the material generated especially for the production of yarns that can satisfy the minimum quality market requirements.

Contrary to the logic, also driven by European and national standards, the market share of textile industry waste is increasingly small. The performance required by the regulations is very high, and sometimes brands require even higher values to protect themselves. The main reason for not choosing recycled textile material is firstly the possible presence of chemical compounds banned by REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals - EU chemicals regulation for health and environmental safety) and the high cost of the material itself compared to virgin or the less mono-fiber composition.

The interviewed actors work with a wide variety of materials (wool, cashmere, blended fibres, etc.), often in small and mixed batches. This diversity makes it challenging to track a specific material, establish a clear flow and define an accurate total quantity. As a result, it is not possible, based on these interviews, to quantify the total annual by-product in tons, whether produced or purchased.

However, the return of material is a counter to this, indicating the percentage of material discarded during processing, which can be reintroduced into the production cycle of the company that produces it or be labelled as by-product or waste. Bearing in mind that it is the market which determines the allocation of one term over another, if there is a textile waste it means that potentially, a buyer is already ready to make his purchase (pre-industrial flows).

The yield of the material, which is worked mechanically and with the knowledge and experience of generations of workers, has remained unchanged over the years and always quite high.

The yield of textile material is an important concept that refers to the amount of final product obtained from a given quantity of raw material, such as fiber or yarn. In other words, it indicates how much output material is produced in relation to the amount of raw material used. This parameter is essential for measuring different factors: production efficiency, costs and opportunities for improvement in manufacturing processes, as well as the amount of waste produced in relation to a given batch in production.

In fact, within the context of sustainability and textile recycling, yield becomes a key parameter for:

- Optimizing waste reduction: the ability to maximize the yield of textile material can lead to a reduction in waste during production. This is crucial for reducing the environmental impact of the textile industry.
- Fiber recovery and opportunities in mechanical and chemical recycling: in textile recycling processes, yield refers to the amount of usable material that can be obtained from recycled textiles. Higher quality, less contaminated textiles offer greater yield when recycled into new yarns or products.
- Design for recycling: increasing the yield of recycled material also depends on the design of the textile product. Using pure or easily separable mixed fibers and opting for less complex manufacturing processes can facilitate recycling and improve the yield of recovered material.

The interviewees collectively referred to a mixed wool textile material with a very high yield, especially considering that it can continuously be reintroduced into the production cycle: companies that process recycled textile materials also collect their own waste to be reintroduced (with a tendency towards infinite cycles) into the production process for manufacturing new products. Data indicates a value of 8-10% waste rate during carding and a 5% waste rate in combing (6–7% weaving with new looms, 9% warping). Typically, if the fibers are of high quality from the outset, the average yield is generally around 95-96%. In some cases, the waste generated during tests and processing trials is also accounted for.

3.6 Data and traceability of textile waste material

Having robust data and traceability for textile waste materials serves multiple critical purposes beyond just sustainability and efficiency in the production processes. These purposes span technical, operational, regulatory, and market-driven needs, providing tangible benefits to various stakeholders across the textile recycling value chain. Just consider the importance of data accompanying material flows once the Product Passport will be widely implemented.

"85% of textile waste/recycled materials lack proper and complete documentation."
"Only 15% of textile companies/supply chain currently implement a sort of traceability systems."

Despite their importance, the current state of data management in the industry is fragmented and inconsistent. Notably, there is no formal regulation mandating the sharing of technical specifications during the sale and purchase of textile waste (post-industrial, pre-consumer and post-consumer). This lack of standardization places the responsibility for compliance on the final product rather than the material flows themselves.

Through interviews with stakeholders in the Prato and Biella textile districts, it becomes evident that the absence of reliable data on waste materials significantly impacts the production chain, market dynamics, and overall trust in the system.

This section explores the **implications of limited data availability** and highlights the opportunities for improvement the data system.

In particular, the data system must be designed to include a set of key data that tracks textile waste materials/families as they enter the processing company. It should also integrate **technological solutions to continuously follow the flow of materials**, updating parameters that characterize the material and translating them into specifications for the final product. In essence, the data system must effectively link the characteristics of incoming waste materials with the specifications of the finished product.

While the ultimate goal is to achieve full traceability throughout the textile product's life — starting from design and raw material selection — the current state of the industry makes this ambition difficult to implement in the short term , the current industry context demands a pragmatic starting point. Today, the moment when textile materials become waste is often the first opportunity to systematically capture data and implement traceability mechanisms. By focusing on this critical juncture, we lay the groundwork for a more comprehensive traceability infrastructure aligned with the future Digital Product Passport. Waste traceability acts as a foundational layer, enabling more accurate sorting, improved circularity along the 5R hierarchy, and ultimately, a smoother integration into end-to-end product tracking. Rather than a compromise, this approach represents a necessary and strategic phase in building a truly circular textile system.

3.6.1 Challenges in Data availability and traceability

The lack of regulation governing the trade of textile waste has created a landscape where the exchange of information is inconsistent and often informal. Buyers frequently rely on trust-based relationships with suppliers to ensure the quality of materials, as there are no standardized requirements for data sharing. This informal approach works to some extent but leaves room for inefficiencies and misunderstandings.

The level of information accompanying textile waste materials varies depending on whether the material originates as post-industrial or as post-consumer waste. Post-consumer materials typically come with minimal data, often lacking details about their provenance or composition. In such cases, the burden of identifying material characteristics falls on the expertise of workers, who employ tactile and visual assessments to determine qualities like fiber type or color.

Conversely, post-industrial and pre-consumer waste tends to have slightly more information available, reflecting its proximity to the production stages. However, even this information is often incomplete, limited to basic details like color, weight, or fiber type.

This inconsistency is particularly pronounced in third-party companies operations, where companies frequently lack any information about whether the materials they handle are recycled, virgin, post-industrial, pre- or post-consumer.

3.6.2 Opportunities for improve the data system for the circular textile value chain

Enhancing data and traceability in textile recycling (pre-treatments and treatments phases) requires a concerted effort to establish industry-wide standards. Introducing mandatory input parameters that follow the material flow, such as composition, color consistency, and fiber length, could significantly improve transparency and trust. Moreover, technological advancements, such as automated sorting systems and digital traceability tools like blockchain, could streamline data collection and sharing processes.

Improving communication between suppliers and buyers is another critical step. Encouraging suppliers to **provide detailed batch-level data**, including pollutant levels and certifications, would help bridge the current information gap.

Automated systems could also play a transformative role in addressing the challenges of small batch sizes and mixed compositions. By integrating data collection into processing stages, recyclers could ensure better traceability and enable downstream users to make more informed decisions about material use.

Case study: Building Trust Without Data – A Practical Reality in Textile Recycling

Overview. One prominent textile recycling company (from Interview 4) highlighted the critical role of trust in the absence of formal data systems. The company works extensively with post-industrial soft waste (fibers, blousses, tops) and relies on established relationships with its suppliers to ensure material quality. While they often receive limited or no technical documentation about the input waste materials for recycling, their long-standing partnerships act as a substitute for traceability.

Challenges. The company rarely receives specifications such as fiber composition, origin, or previous processing treatments. The only consistent data points are material weight and general categories like blousses or tops. Without detailed data, the company struggles with variability in material quality. For example, excess vegetable matter in the input materials reduces processing efficiency.

Solutions and Improvements. Workers leverage experiential techniques to assess material quality. For instance, visual inspections and tactile analysis help them classify materials and predict their suitability for specific applications.

"Our hands and eyes have replaced the missing data"

Small batches of materials are tested manually before large-scale processing. This includes checking fiber fineness and tensile strength to align with customer specifications.

Trust with suppliers is crucial. The company only works with long-term partners whose materials have consistently met informal standards.

The company expressed interest in adopting Digital solution systems like blockchain or AI-based traceability platforms. These tools could bridge the data gap by providing real-time updates on material properties throughout the supply chain.

3.7 Analysis and laboratory testing of incoming material

Despite the mutual trust between companies and suppliers of waste/secondary raw materials, many stakeholders report that before accepting the required quantity of material, **they first inspect a sample**. This phase, commonly referred to as the "Reception" phase, is primarily conducted using visual and experiential methods developed through decades of expertise in the textile sector. For example:

Smell: Helps identify the origin of the wool.

Hearing: The sound produced when handling the material can indicate its thickness.

Lighter test: Burning the material and observing the flame's color can provide insights into its composition. If the material is natural, it produces a carbonaceous residue when it burns; if it is synthetic, it doesn't burn but melts.

Gloss: The shinier the material, the newer or less processed it likely is.

Touch: A soft and fluffy texture suggests that the wool is purer rather than blended.

To address the lack of comprehensive data, particularly regarding REACH compliance, companies conduct internal analyses if they have a laboratory. Otherwise, they outsource testing to external laboratories, particularly to confirm the composition and verify compliance with the REACH regulation on chemicals. The subcontractors interviewed confirmed that their tests primarily focus on the oils used in processing, and occasionally they check for the presence of viscose, which can complicate wool processing.

In any case, the nature and frequency of tests depend on the intended use of the textile waste material. For instance, materials destined for thermo-acoustic insulation panels undergo different and less frequent testing compared to those intended for fashion industry applications.

As with all textile materials, recycled materials must also comply with the REACH regulation. This topic is the subject of ongoing debate since applying the same chemical restrictions to recycled materials as to virgin materials, poses significant challenges to the adoption and growth of recycled textile usage.

Recycled textile materials often originate from garments and fabrics produced many years ago, when the current chemical restrictions and safety standards were not in place. As a result, it is common to find elevated levels of substances that are now classified as harmful.

Another issue is the heterogeneity of the recycled material, which presents two challenges:

- It is difficult to achieve consistent and reliable measurements for harmful substances due to the varied nature of the material.
- Given that recycled materials often come from mixed collections, it is challenging to precisely identify the substances used in the original production processes, compounded by a lack of traceability.

Consequently, ensuring that recycled materials are free from substances banned under current regulations can be complex. Some interviewees suggested that shifting the compliance control process to the spinning stage (or to the spinning preparation processes) might be beneficial. However, this would entail significant costs, especially if the material exceeds the allowable limits and must be discarded.

That said, non-compliance with certain parameters does not always result in the cancellation of a purchase. Many companies have developed internal “recipes” that vary depending on customer orders and available stock. These formulas allow the diluted use of textile waste material for recycling, thereby mitigating some compliance challenges.

The lack of reliable data on the chemical composition of recycled materials presents a significant challenge to the accuracy of labeling, a critical requirement for compliance with many regulatory frameworks. Without precise chemical profiles, products may fall short of meeting the transparency standards demanded by both the market and consumers, potentially undermining trust in recycled materials.

Furthermore, each recycling cycle carries the inherent risk of chemical accumulation within the materials. Undesirable substances, such as residual dyes, flame retardants, or APEOs (Alkylphenol Ethoxylates), may not be fully eliminated during the recycling process. Over successive cycles, these harmful chemicals can concentrate to levels that pose environmental and health concerns. This underlines the need for robust laboratory testing protocols that not only detect such substances but also ensure their reduction or elimination through improved recycling methodologies.

The certification of imported textile materials still needs to be addressed. The lack of controls or certifications upon entry into Europe remains a significant issue.

By addressing these gaps through rigorous chemical analysis and transparent data sharing, the industry can enhance both the safety and market acceptance of recycled textile materials, fostering greater confidence in their use across applications.

REACH Regulation for Recycled Textile Materials managing

The REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulation, established by the European Union, is designed to protect human health and the environment from risks posed by chemicals, while promoting innovation and competitiveness in the chemical industry. Implemented in 2007, REACH requires manufacturers, importers, and downstream users to register and evaluate chemical substances to ensure safe usage. The regulation applies across the EU and encompasses all substances, including those used in textile manufacturing and recycling.

REACH mandates strict controls on hazardous chemicals, sets limits on specific substances, and enforces comprehensive documentation and testing to ensure that materials meet safety standards. Its provisions extend to both virgin and recycled textile fibers, demanding traceability and compliance even when the chemical history of recycled inputs may be unclear. The regulation has become a cornerstone for ensuring that textiles, whether new or recycled, adhere to stringent safety requirements in global markets.

It plays a critical role in the handling and processing of recycled textile materials, as highlighted by several interviewees. While REACH primarily aims to ensure chemical safety in products across the European Union, its application to recycled textiles presents unique challenges. For instance, many recycled materials, particularly those derived from post-consumer waste, lack detailed documentation about their chemical composition or previous treatments, creating gaps in compliance and traceability.

Interviewees pointed out that recycled fibers often undergo blending processes to dilute or neutralize the presence of restricted substances, such as APEOs or heavy metals found in dyed fabrics. However, achieving full compliance remains difficult, especially for smaller companies without advanced testing capabilities. Furthermore, the variability in input materials complicates the consistent application of REACH standards, as fibers from different sources often exhibit varying chemical residues.

For textile recyclers, the introduction of mandatory REACH-compliant certifications, such as GRS (Global Recycled Standard), has been both a facilitator and a barrier. While it ensures safer, standardized products, it also increases operational costs and administrative burdens. In some cases, material that might otherwise be recyclable is discarded due to the inability to meet REACH criteria, as the cost of testing exceeds the material's value.

To address these challenges, interviewees suggested the development of a tailored framework within REACH for recycled materials. This could include simplified testing protocols, enhanced traceability systems, and a focus on harmonizing standards to ensure that recycled materials can compete with virgin fibers in both safety and market acceptance.

Case study: Managing REACH compliance in Recycled Textile Materials

Overview. A textile recycling company operating as a third-party company (Interview 9) provides a compelling example of how REACH compliance is managed in the industry. This company processes recycled fibers primarily sourced from client-selected materials, including both pre- and post-consumer waste. While the responsibility for initial material selection rests with their clients, the company undertakes specific steps to ensure compliance with REACH during processing.

Key Actions Taken for REACH Compliance

Chemical Testing of processing aids:

The company conducts targeted tests on the oleants (lubricants used during spinning processes) to ensure they meet REACH requirements. These tests are crucial because oleants can potentially introduce restricted substances into the final product.

Traceability challenges:

Despite not being directly responsible for sourcing, the company highlighted the difficulty of tracing the chemical history of the materials it receives. The blended nature of fibers, particularly in recycled inputs, complicates the identification of prior treatments or potential chemical residues. This issue is especially prominent with post-consumer textiles, which may have been treated with substances like PFAS (per- and polyfluoroalkyl substances) or APEOs (alkylphenol ethoxylates).

Client-Driven Material Selection:

Materials are provided by their clients, who dictate the blend compositions. While this simplifies sourcing responsibilities for the company, it places an additional burden on ensuring downstream compliance with REACH standards. For example, when working with wool-polyester blends, special attention is paid to potential legacy chemicals.

Adapting to Evolving Standards:

The company expressed concerns about the evolving requirements under REACH and related regulations. For instance, stricter testing thresholds and new chemical bans have necessitated ongoing adjustments to processes and supplier relationships.

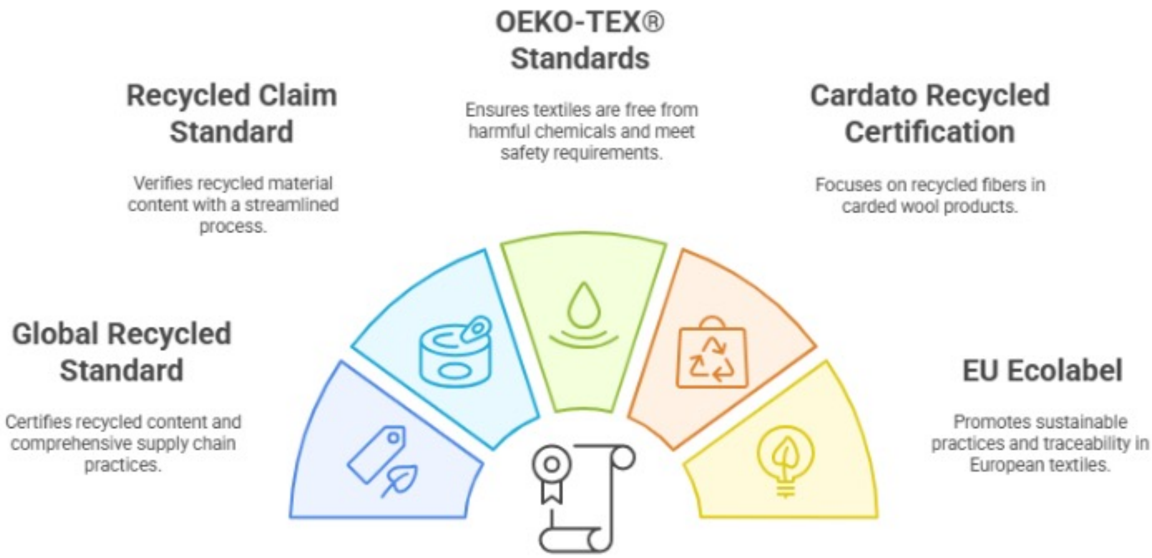
3.8 Certifications for textile waste material for recycling and for textile recycled materials/products

In the context of textile recycling, certifications serve as essential tools for setting parameters for the flows of recycled materials, promoting traceability, and ensuring compliance with both environmental and social standards. As discussed in the previous chapters, the flow of – first waste and then recycled textile materials - often lacks uniformity in terms of data and traceability. Certifications act as a framework to bridge this gap, providing a structured approach to evaluating and managing material flows while enhancing transparency across the value chain.

Certifications not only ensure that recycled textile materials meet rigorous standards but also provide a pathway for companies to differentiate themselves in a competitive market.

Among the most commonly requested certifications in the textile recycling industry are:

- **Global Recycled Standard (GRS)**: Widely regarded as the gold standard, the GRS certifies both the recycled content of a product and the social, environmental, and chemical practices employed throughout the supply chain.
- **Recycled Claim Standard (RCS)**: Focused on verifying the amount of recycled material in a product, the RCS offers a streamlined certification process for companies that do not require the additional environmental or social criteria covered by the GRS.
- **OEKO-TEX® Standards**: Including certifications like MADE IN GREEN and STANDARD 100, OEKO-TEX ensures that textiles are free from harmful chemicals and meet strict environmental and safety requirements.
- **Cardato Recycled Certification**: A unique certification developed in Prato, Italy, specifically for carded wool products, it emphasizes the use of recycled fibers, evaluating the enviromental impact through the Life cycle Analysis (LCA)..
- **EU Ecolabel**: As the official European certification for eco-friendly products, the EU Ecolabel promotes sustainable practices, including reduced environmental impact and traceability, for textile products across Europe.



The adoption of these certifications has accelerated as global consumers and regulatory bodies demand greater accountability from manufacturers and recyclers. These frameworks are essential for aligning with broader sustainability goals, such as the European Green Deal and the United Nations Sustainable Development Goals (SDGs).

From the interviews conducted within the Prato and Biella textile districts, it became evident that certifications are more than compliance tools; they are operational enablers.

However, stakeholders expressed a strong need to consolidate existing certifications under a unified framework to reduce complexity and certification costs. For instance, integrating standards like the GRS) and RCS under a single certification body could streamline processes while maintaining rigorous standards.

Additionally, several stakeholders emphasized the importance of making certifications more technically grounded. In particular, there was a recurring call to integrate Life Cycle Assessment (LCA) methodologies into broader certification schemes. The Cardato Recycled Certification in the Prato district exemplifies this approach: it uses LCA as a core evaluation tool, demonstrating the potential of certifications that rely on scientific and measurable indicators. Some interviewees noted that such technical validation not only increases the credibility of certifications but could also better meet the demands of more advanced markets and regulatory frameworks.

However, while region-specific certifications like Cardato Recycled have shown the value of technical rigor, their limited recognition beyond local markets highlighted the need for globally harmonized certifications that maintain high scientific standards while ensuring international acceptance.

Another significant issue highlighted by recyclers concerns the perceived inequity in the enforcement of certification standards globally. Several interviewees expressed frustration that, while local companies in Europe undergo rigorous and costly certification processes - often exceeding European regulatory requirements - materials imported from regions such as China frequently arrive already certified without equivalent verification efforts. Stakeholders voiced strong concerns about the credibility of such certifications, questioning whether proper traceability and compliance are being genuinely ensured. This perceived unfairness undermines trust in the certification system and creates a distorted competitive landscape for local recyclers who invest heavily in meeting strict standards.

Moreover, the complexity of managing certifications is amplified by regulatory frameworks such as the REACH regulation. Several recyclers pointed out that REACH criteria are currently applied equally to virgin and recycled materials, creating significant compliance challenges for recyclers. This issue, already discussed in the previous section, continues to be a major barrier, as recyclers must meet chemical safety requirements originally designed for virgin raw materials - often without the same level of process control. The misalignment between regulatory expectations and the specific realities of recycling operations contributes to additional costs, administrative burdens, and market barriers for recycled products.

In parallel, interviewees stressed the general need to simplify certification management: requirements often exceed local and European regulations, creating additional burdens for companies, particularly small and medium-sized enterprises. Certification inspections frequently go beyond the demands of existing European legislation, adding complexity and cost to compliance efforts. To support wider adoption, particularly among smaller companies, it is necessary to find ways to reduce certification costs or increase financial support.

A recurring theme in the interviews was the complexity of addressing social compliance requirements within certification frameworks. Social criteria, such as compliance with labor laws and wage standards, often involve intricate documentation and inspections. Despite these challenges, certifications remain a crucial tool for aligning recycled textile materials with market needs. By ensuring that materials meet stringent environmental and social standards, certifications instill confidence among end-users and open pathways for recycled materials in high-value applications.

Textile Exchange, which oversees GRS, is working on expanding certification coverage to include intermediate materials such as blousses, laps, and tops, which are currently excluded.

Company system adjustments for obtaining and maintaining GRS certification

- Dedicated storage areas for GRS materials.
- Documentation and record-keeping aligned with GRS templates.
- A material balance sheet to track inputs and outputs.
- Compliance with stringent social requirements, including labor standards and wage documentation.

3.8.1 Challenges in certifying intermediate products: the case of "Laps", "Tops", and "Blousses"

An additional concern raised during the interviews involves the difficulty of certifying certain types of scraps collected during the textile production processes, specifically the "laps", "tops" and "blousses".

In the textile recycling districts of Prato and Biella, long-established industrial jargon distinguishes between specific categories of materials that play a crucial role in regeneration. Laps, tops, and blousses, often sorted by color and quality, are textile scraps that are redirected into mechanical recycling. These forms of textile input, as semi-finished intermediates, are highly valued within the recycling process because they allow smoother reintegration into spinning and regeneration stages.

These materials, commonly produced during early stages of textile recycling and preparation for spinning, are critical within the recycling process yet are not explicitly recognized in the GRS certification scope governed by Textile Exchange.

The primary reason for their exclusion lies in the structural design of the GRS, which focuses on certifying processes and products that are closer to final consumption stages, such as yarns, fabrics, and finished garments, where traceability, recycled content verification, and auditing procedures are more straightforward and standardized. Intermediate products like laps and tops, by contrast, are early-stage semi-finished materials whose recycled content is harder to verify independently, particularly considering potential mixing or blending during subsequent processing stages.

Moreover, Textile Exchange maintains a streamlined list of materials and products eligible for certification to ensure consistency and manageability across audits. This approach, while administratively efficient, has created challenges for recyclers, especially those who specialize in producing these intermediate forms and who, despite effectively using recycled fibers, find themselves unable to obtain GRS certification for their output. As a result, their access to markets that require GRS-certified inputs is constrained.

Stakeholders from textile districts such as Prato and Biella expressed a strong desire for certification bodies to expand their coverage to include key intermediate products. They emphasized that recognizing these materials would not only validate the role of recyclers earlier in the value chain but also improve the traceability and credibility of recycled textile flows overall.

This feedback aligns with the broader requests for greater flexibility, scientific rigor (e.g., through Life Cycle Assessment), and inclusivity in future iterations of certification standards, thereby ensuring that all critical stages of the recycling process are adequately acknowledged and supported.

In any case, their exclusion does not reflect a lack of relevance but rather the greater complexity of independently verifying recycled content at early stages of the value chain.

3.9 Economic burden of managing Textile Waste for companies

Managing textile waste entails a multifaceted cost structure, as revealed by the interviews conducted. The first component involves personnel costs, which include both on-site workers managing waste collection and sorting and office staff responsible for administrative tasks such as regulatory compliance, documentation, and supplier coordination. These operational costs are critical, as they often dictate the efficiency of the overall waste management process.

Another significant expense arises from the service provider responsible for waste collection. This cost varies widely, ranging between €0.17 and €0.40 per kilogram, depending on market dynamics. Higher costs are observed when the supply of textile waste exceeds the demand for recyclable or reusable materials, reflecting the influence of market saturation on collection fees.

Temporary storage space for holding waste materials prior to collection represents another essential cost. Depending on production volumes and logistical constraints, companies may need to allocate dedicated warehouse areas, leading to additional operational overheads. This storage requirement can become particularly burdensome during production peaks.

Some companies also incur *membership fees* to collect consortia or industry-specific organizations (PMOs), which facilitate collective waste management efforts, advocacy, and access to shared services. While these consortia can potentially reduce overall disposal costs through economies of scale, they introduce fixed membership fees that must be carefully weighed against the benefits.

An additional financial consideration arises when businesses aim to ensure traceability and compliance with sustainability standards, such as obtaining and maintaining GRS certification. This certification, increasingly demanded by the market, imposes costs related to auditing, documentation, and compliance monitoring.

Moreover, the forthcoming implementation of EPR schemes introduces new financial obligations for textile producers. Under the revised EU Waste Framework Directive, all member states are required to establish EPR systems for textiles, mandating producers to cover the costs associated with the collection, sorting, and recycling of textile waste. These costs will be determined based on eco-modulation principles, where fees are adjusted according to the environmental performance of the products, encouraging the design of more sustainable and recyclable textiles.

In Italy, the Ministry of Environment launched a public consultation in April 2025 on a draft decree to establish a national EPR system for textiles. The proposed decree outlines obligations for producers to finance and organize the EoL management of textile products, including clothing, footwear, accessories, and home textiles. Producers will be required to adopt eco-design strategies, use sustainable materials, and ensure transparency and traceability throughout their supply chains. Compliance will involve either individual systems or participation in collective schemes managed by PROs.

Ultimately, the economic burden of managing textile waste is not static but rather subject to multiple external factors, including production cycles, market demand for recycled materials, and evolving regulatory requirements.

Cost Component	Description
Personnel Costs	Operational staff handling waste on-site and administrative staff managing compliance and logistics.
Waste Collection Fees	Costs incurred from the service provider responsible for collecting the waste (ranges from €0.17 to €0.40/kg).
Temporary Storage Costs	Expenses related to dedicated areas for holding waste before collection.
Consortium Membership Fees	Fixed costs associated with joining industry organizations to optimize waste management.
Certification Costs (e.g., GRS)	Auditing and compliance costs to ensure traceability and market acceptance of waste materials.
EPR compliance fee	*Under the upcoming EPR regulations, producers will be required to pay an EPR compliance fee, an environmental contribution designed to cover the full lifecycle management of textile products placed on the market*

Table 6: Relevant cost components of the overall company cost for managing textile waste

Beyond the costs incurred in managing textile waste, it is equally important to consider the **economic value that waste materials can generate**, particularly when they re-enter the market as recycled fibers or material for recycling. The average resale value of textile materials for recycling - as shown in the accompanying table - provides a tangible indicator of this potential. However, this value is not intrinsic to the waste alone: it is shaped by the **original quality of the fiber**, the **efficiency and traceability of the recovery process**, and the **operational investments** made by companies across the waste management chain.

This perspective calls for a broader **life-cycle cost approach**, where waste is not seen solely as a disposal problem but as part of a dynamic system of material valorization. In this context, the role of EPR schemes becomes pivotal. With eco-modulation mechanisms at their core, future EPR systems will assign differentiated fees based on the environmental performance and design of textile products — rewarding recyclability, durability, and traceability. This will create a direct economic incentive to design products that retain value beyond their primary use, while encouraging more cost-effective and transparent waste management systems.

The interplay between **fiber quality, process efficiency, and regulatory incentives** will ultimately define the net economic burden - or benefit - of textile waste management. Companies that understand and optimize this balance will be better positioned to not only comply with future regulations but also unlock new forms of value in circular textile markets.

Category	Composition / Characteristics	Estimated Value	Intended Use	Notes
Selected cashmere	Knitwear, sorted by color	Up to 21,000 €/t	High-quality regenerated yarns	Highest value for fine fibers, used in premium regeneration.
Mixed colored wool	Wool of various colors, requires sorting	~900 €/t	Mechanical recycling	Needs additional color-based sorting.
Lightweight cotton blend	Lightweight fabrics, cotton-based blends	~100 €/t	Mechanical recycling	Used for fiber recovery or industrial applications.
Heavyweight cotton blend	Heavyweight fabrics cotton-based	~30 €/t	Lower-grade applications	Lower value, suitable for low-end reuse or downcycling.
Closed bag (first quality)	Unsorted used garments, first quality	~100 €/t	Reuse or recycling selection	Not pre-sorted.
Closed bag (second quality)	Unsorted used garments, second quality	0 €/t	Recycling or disposal	Lower price due to inferior quality.
Selected woollen fabrics	Wool sorted by color and composition	~1,000 €/t	Recycled yarns	Requires accurate manual sorting.
Monochrome pre-consumer scraps	Clean industrial waste, uniform in color	Up to 1,200 €/t	High-quality mechanical recycling	Ideal for new textile production without dyeing.

Table 7: Indicative waste value after fiber shredding, subject to variations linked to market trends, sorting practices, and fiber composition.

3.10 Workability of textile waste materials for recycling

The workability of recycled fibers presents a set of specific challenges compared to processing virgin raw materials, as emphasized by the interviewees. The impact of recycling on material properties is particularly noticeable in wool. In general, recycled wool fibers tend to be significantly shorter than virgin wool fibers, resulting in a decline in yarn strength, elasticity, and overall textile performance. The difference is less pronounced in cotton processing, where fiber length is naturally shorter and the transition to recycled material is comparatively less disruptive. However, across all fiber types, the blending methods used to create recycled yarns critically influence the ease of processing. For example, earlier attempts at tri-blends (three-fiber blends) faced considerable difficulties, as mismatched fiber characteristics - such as staple length, fineness, and tensile strength, led to uneven yarn quality and increased production defects.

A further complication arises when recycled wool is blended with cellulosic fibers such as cotton or viscose: these combinations are particularly difficult to process because the different behaviors of protein-based and cellulose-based fibers require careful handling. When wool is blended with cellulose fibers, lubricants (known as “oleants”) must be applied during spinning to facilitate fiber cohesion and reduce breakage. If suppliers do not properly inform manufacturers about the exact composition of the recycled material, especially regarding the presence of cellulose, significant processing issues may occur, leading to machinery downtime and product inconsistency.

Nevertheless, it is worth noting that in many subcontracted manufacturing operations (“conto terzi” contract manufacturing), operators often do not notice the presence of recycled content within blends unless it is specifically certified, such as through the Global Recycled Standard (GRS). Without clear certification, recycled fibers can be invisible during processing, particularly when mixed with virgin material in low proportions.

Today, recycled materials are often incorporated into production in very small batch sizes, typically through blending with virgin fibers. These small lots require frequent machine adjustments and recipe changes, significantly slowing down production cycles. Each batch may necessitate recalibration of spinning parameters such as twist levels, tension settings, and lubricant application rates. This adds both time and complexity to production lines originally optimized for large, consistent runs with virgin materials. Furthermore, the variability in recycled fiber quality—due to differences in the input waste, previous dyeing treatments, and fiber aging—makes it challenging to standardize production processes, increasing the risk of defects and inconsistencies.

In conclusion, while the use of recycled fibers is growing due to regulatory pressures and market demand for sustainability, their successful integration into production lines requires technical adjustments, process flexibility, improved material information sharing, and a high level of collaboration between fiber suppliers, spinners, and weavers.

3.11 Gaps in the Textile Recycling Value Chain: Findings from Interviews

This section aims to systematically review the gaps previously identified through the analysis and reworking of stakeholder interviews. By presenting the gaps in a more structured and organized way, the objective is to facilitate a quicker and more effective reflection for the reader, building upon the work already carried out in the earlier phases.

The main goal is to map and highlight the points within the value chain that are considered ready for targeted interventions to further drive the transition towards circularity.

The starting point of this analysis was the new feedback gathered during the interviews, which provided an updated and direct view of the operational challenges, priorities, and opportunities in the recycling sector. Building on this fresh evidence, we also leveraged the previous work carried out within the RegioGreenTex project, particularly under Work Package 1 (Deliverable D1.3) – as previously mentioned - which had already produced a structured mapping and initial gap analysis of circular textile value chains.

In the earlier work, a macro-classification of gaps referring to the mechanical wool value chain had been established along two dimensions:

Type of Function Affected:

- Core Functions Gaps (gaps related to key activities in the value chain)
- Support Functions Gaps (gaps related to services supporting the value chain, such as laboratories, machinery suppliers, etc.)
- Policy Instruments Gaps (gaps related to standards, regulations, and policy frameworks)

Thematic Clusters: In addition to the functional classification, gaps were grouped into five main thematic categories based on their nature and impact. In this analysis, we have:

- Reconfirmed the existing five thematic clusters (Infrastructure/Technical/Technological Gaps; System/Organisation Gaps; Cultural/Skills gaps in circular practices and products; Skills gaps in digital solutions; Regulatory Gaps);
- For this iteration, we consolidated Cultural and Skills Gaps in Circular Practices and Products and Skills Gaps in Digital Solutions into a single unified cluster named “Cultural, Skills, Awareness and Human Resources” to reflect their shared focus on capacity building, learning, and behavioral change across the value chain.
- Identified and introduced a new cluster, specifically focused on Market and Economic Gaps, which emerged strongly through the latest interviews.

Building on that framework, the current analysis introduces three new dimensions:

- **Priority Category**: Each gap is assigned a level of priority (High Priority, Strategic Challenge, or Lower Priority) based on its systemic impact and practical feasibility.
- **Macro-Phase of the Value Chain**: The gap is mapped to the specific segment of the value chain it affects (e.g., sorting, treatments, pre-treatments, market access, etc.).
- **Relevance Beyond Recycled Wool**: Each gap is assessed to determine whether it is specific to the mechanical wool value chain or generalizable across the broader textile sector.

In the following sections:

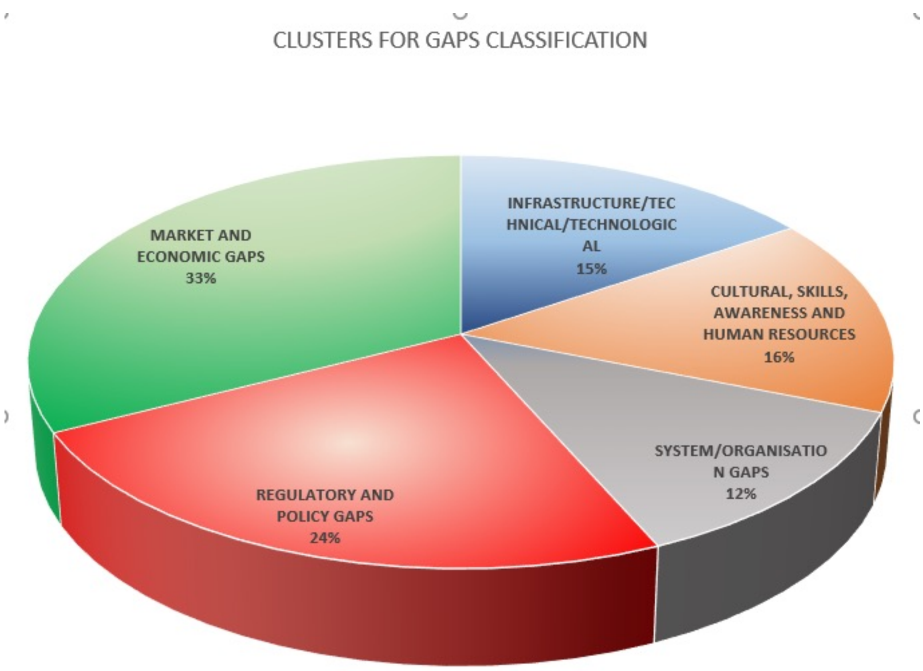
- We present the gaps newly identified or validated through fieldwork.
- We classify these gaps according to four dimensions (five clusters, priority category, macro-phase of the Value Chain, Relevance beyond recycled wool).
- We highlight critical areas for action to foster systemic change towards circularity.

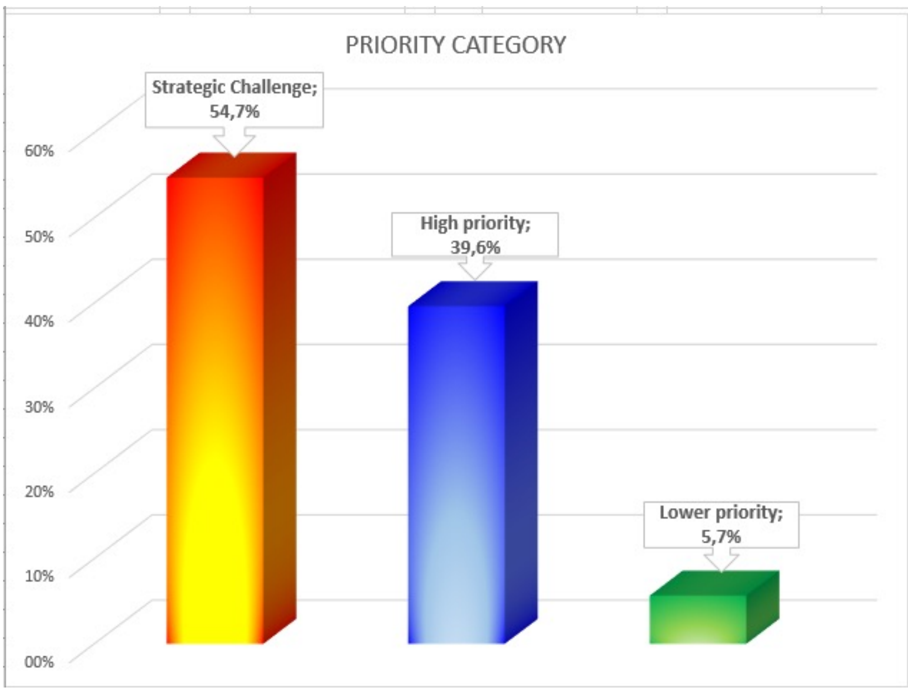
This updated framework wants to equipe stakeholders with a practical tool for informed, targeted, and high-impact decision-making.

	CLUSTERS FOR GAPS CLASSIFICATION					PRIORITY CATEGORY	MACRO-PHASES OF THE VALUE CHAIN	RELEVANCE BEYOND RECYCLED WOOL VALUE CHAIN
	INFRASTRUCTURE/ TECHNICAL/ TECHNOLOGICAL	CULTURAL, SKILLS, AWARENESS AND HUMAN RESOURCES	SYSTEM/ ORGANISATION GAPS	REGULATORY AND POLICY GAPS	MARKET AND ECONOMIC GAPS			
Sorting is often performed manually, limiting scalability and efficiency.	X			X		Strategic Challenge	Sorting	Yes
Lack of a company/organization offering large-scale sorting services for textile waste.			X	X	X	Strategic Challenge	Sorting	Yes
Limited adoption and availability of automated sorting technologies.	X	X				Strategic Challenge	Sorting	Yes
Difficulty removing hard components from garments (buttons, zippers, etc.).	X					High priority	Pre-treatments	Yes
Lack of carbonization facilities for wool.	X		X	X		High priority	Pre-treatments	No
No mandatory classification systems or technologies available for internal separation of heterogeneous textile waste.	X	X	X	X		Strategic Challenge	Sorting	Yes
Collection of textile waste occurs when full truckloads (20–25 tons) are available, excluding smaller suppliers.								
Minor technical inconsistencies occur in recycled yarns (e.g., airjet yarns).	X					Lower priority	Treatments	No
Despite smooth processing (expecially treatment processes), there are no standardized input testing protocols or documents.		X	X	X		High priority	All value chain	Yes
Circular design methodologies are unclear to most SMEs.		X	X	X	X	High priority	Design	Yes
There is a shortage of young professionals trained in wool sorting.		X			X	High priority	Sorting	Yes
No dedicated training for emerging circular roles (e.g., eco-designers, recycling technicians).		X			X	High priority	All value chain	Yes
Risk of generational knowledge loss due to aging workforce. Technical expertise is concentrated in a few historical actors only.		X	X		X	Strategic Challenge	All value chain	No
Lack of full mapping of companies involved in the long recycling chain. The system is still disconnected; companies are unaware of each other's capabilities.			X		X	High priority	All value chain	Yes
Difficulty sharing production/manufacturing data across companies.	X		X		X	Strategic Challenge	All value chain	Yes
Strong regional differences in implementation of textile collection legislation.			X	X	X	High priority	All value chain	Yes
Absence of a supporting industrial system and market incentives for textile "reuse".				X	X	Strategic Challenge	Market access	Yes
No clear legal distinction between "waste" and "by-product."				X	X	High priority	Collection, sorting	Yes
End-of-Waste status is often assessed subjectively by local authorities.				X	X	High priority	Collection, sorting, pre-treatments	Yes
Lack of legal clarity regarding the classification of sorting/collecting entities (e.g., craft vs. industry).				X	X	High priority	Collection, Sorting	Yes
Regulations prioritizing PET-to-PET recycling reduce the availability of recycled PET for use in textile applications				X	X	Strategic Challenge	Market access	Yes
Recycled materials are subject to double VAT taxation, considered unconstitutional by some companies.				X	X	Strategic Challenge	Market access	Yes
Regulatory and certification (e.g. GRS) burdens increase significantly for firms with more than 10 employees, including added social compliance requirements				X		High priority	All value chain	Yes
No harmonized standard exists for measuring sustainability of textile products.		X	X	X	X	Strategic Challenge	Market access	Yes
"Circular" certifications are seen as redundant and overlapping. Lack of integration among certification systems increases costs and complexity.				X	X	Strategic Challenge	All value chain	Yes
Many certified materials (e.g., imported from China) are perceived as unreliable.				X	X	Strategic Challenge	Market access	Yes
Companies are generally uninformed about key EU regulations.		X				High priority	All value chain	Yes
Demand for recycled textile materials has declined sharply.				X	X	Strategic Challenge	All value chain	Yes
Disposal of textile waste can cost up to €0.40/kg — almost 25% the cost of virgin yarn.				X	X	Strategic Challenge	Collection, sorting	Yes
Waste textiles no longer have market value and are often sent to landfill.	X	X		X	X	Strategic Challenge	All value chain	Yes

	CLUSTERS FOR GAPS CLASSIFICATION					PRIORITY CATEGORY	MACRO-PHASES OF THE VALUE CHAIN	RELEVANCE BEYOND RECYCLED WOOL VALUE CHAIN
	INFRASTRUCTURE/ TECHNICAL/ TECHNOLOGICAL	CULTURAL, SKILLS, AWARENESS AND HUMAN RESOURCES	SYSTEM/ ORGANISATION GAPS	REGULATORY AND POLICY GAPS	MARKET AND ECONOMIC GAPS			
Virgin fibers remain cheaper and more accessible than recycled ones.	X			X	X	Strategic Challenge	All value chain	Yes
No economic incentives for using or producing recycled textile materials.				X	X	High priority	All value chain	Yes
Recyclers must stock large volumes of material to match the color demands of brands and fast fashion for final recycled textile products					X	High priority	All value chain	Yes
Sectors like construction avoid recycled textiles for legal or health reasons.				X	X	Strategic Challenge	All value chain	Yes
The supply of recycled materials exceeds market absorption capacity.					X	High priority	All value chain	Yes
Global logistics strategies (e.g., sending to India/Pakistan for sorting) lower costs but increase environmental impact.	X		X		X	Strategic Challenge	Sorting	Yes
Lack of consumer awareness regarding circularity in textiles.		X			X	High priority	All value chain	Yes
Brands often practice greenwashing—using sustainability rhetoric without real action.		X			X	High priority	All value chain	Yes
Low awareness of the environmental pros and cons of different recycling practices among producers and consumers		X			X	High priority	All value chain	Yes
General distrust in certifications and traceability systems.		X			X	Strategic Challenge	All value chain	Yes
85% of textile waste lacks complete documentation or traceability.	X	X	X	X	X	Strategic Challenge	All value chain	Yes
No standardized requirement to share technical data in waste/material trades.				X	X	Strategic Challenge	All value chain	Yes
Material composition is often unknown, especially for post-consumer inputs.	X				X	Strategic Challenge	All value chain	Yes
Buyers rely on manual tactile tests (e.g., smell, burn, touch) due to missing data.	X	X	X	X	X	Strategic Challenge	All value chain	Yes
Inability to track the presence of harmful chemicals (e.g., APEOs, PFAS) due to lack of history.	X	X	X	X	X	Strategic Challenge	All value chain	Yes
Recycled fibers are often short, resulting in lower quality yarns.	X					Lower priority	Treatments	No
Complex blends (e.g., wool-viscose) create processing inefficiencies.	X					Lower priority	Treatments	No
Lack of CE marking prevents recycled textiles from entering regulated high-value markets				X	X	Strategic Challenge	All value chain	Yes
Regulatory standards (e.g., REACH) apply equally to virgin and recycled fibers, creating unfair barriers.				X	X	Strategic Challenge	All value chain	Yes
Complexity in certifying semi-finished recycled products (e.g., tops, laps, blouses).				X	X	Strategic Challenge	All value chain	No
Many companies do not know or classify the types of material for recycling they use/treat ("families").	X	X			X	High priority	Treatments	No
Material streams are small, mixed, and highly variable — limiting efficiency.	X		X		X	High priority	All value chain	Yes
Sorting systems (manual or automated) struggle to handle high heterogeneity of inputs.	X					Strategic Challenge	Sorting	Yes
Market dominance of traders reduces local control over sorting and material sourcing		X			X	Strategic Challenge	Market access	Yes

Table 8: Structured overview of the gaps identified through stakeholder interviews


CLUSTERS FOR GAPS CLASSIFICATION
INFRASTRUCTURE/TECHNICAL/TECHNOLOGICAL
15%
CULTURAL, SKILLS, AWARENESS AND HUMAN RESOURCES
16%
SYSTEM/ORGANISATION GAPS
12%
REGULATORY AND POLICY GAPS
24%
MARKET AND ECONOMIC GAPS
33%


PRIORITY CATEGORY
Strategic Challenge; 54,7%
High priority; 39,6%
Lower priority; 5,7%
60%
50%
40%
30%
20%
10%
00%

3.11.1 Reflection on the Comprehensive Gap Table

This matrix highlights the **multi-dimensional nature** of the barriers slowing down the transition to a circular textile value chain. By classifying each gap according to functional categories, phase of the value chain, systemic relevance, and generalizability beyond recycled wool, it becomes clear that the path toward circularity requires more than just technological upgrades — it demands systemic **alignment** across policies, market forces, cultural norms, and industrial capabilities.

Several important insights emerge:

- **Most critical gaps are cross-cutting**: The majority of high-priority issues — such as traceability, lack of design competencies, certification burdens, and market imbalances — are not unique to recycled wool, but affect the entire textile sector. This confirms that strategic interventions can and should aim at sector-wide transformation.
- **Sorting and pre-treatment remain major bottlenecks**: Gaps related to sorting (manual processes, lack of automation, and high material heterogeneity) are consistently rated as strategic challenges. These technical bottlenecks have a high impact but require significant coordination, investment, and technological maturity to solve.
- **Regulatory issues dominate strategic challenges**: The column for "Regulatory and Policy Gaps" is heavily populated with high-priority or strategic challenge tags — from end-of-waste ambiguity to certification burdens. This reflects how regulatory uncertainty acts as a structural brake, even when technological solutions exist.
- **Market mechanisms are not aligned with circular goals**: A lack of economic incentives, combined with higher costs for recycled materials and limited demand in downstream sectors, suggests that **the business case for circularity is still weak**. Policy and procurement levers will be critical here.
- **Human and cultural dimensions are under-addressed but highly actionable**: Gaps related to skills, generational turnover, and awareness are widespread. The good news is that these are often high-feasibility gaps — they can be addressed relatively quickly through training, campaigns, and local innovation policies.

In conclusion, the table offers not just a diagnosis but a blueprint for strategic planning. It helps stakeholders identify where to invest first, where collaboration is most urgent, and where policy must evolve to unlock progress. The challenge ahead is to activate this roadmap with coordination, shared vision, and tailored actions for each segment of the textile economy.

4. Exploring Textile Recycling Technologies

This chapter draws directly from the *Technology Scouting for Textile Waste Management* report developed within the RegioGreenTex project. While the current section provides a curated synthesis of its findings, the full scouting report is available as a stand-alone resource for stakeholders seeking deeper technical detail on the technologies, actors, and innovation dynamics shaping the textile recycling landscape.

The report and the following paragraphs present an assessment of the actors — companies, research groups, and technology providers — currently developing and implementing technologies for textile recycling, starting from collection and sorting phases and extending across the entire value chain. Rather than offering a static classification of processes, it investigates who is building what, for which materials, at what scale — and how far each initiative has progressed toward operational maturity. The analysis touches on diverse solutions: fiber identification and classification, mechanical and chemical recycling methods, hybrid processes, and downstream transformation steps.

While grounded in the case of wool recycling in the textile districts of Prato and Biella — regions that are central to the analysis presented in this report — this chapter speaks to broader industrial ecosystems. Similar challenges arise wherever systems are preparing to handle the recycling of complex, heterogeneous textile flows: blends, coatings, degraded fibers, and garments with multiple lives behind them. These realities demand technological ecosystems that are not only efficient, but **adaptive**.

One key insight that emerged throughout this assessment is that the challenge of textile recycling is rarely about individual technologies in isolation. Rather, it lies in the **integration** of multiple steps — each with its own level of maturity (TRL), each subject to its own technical and economic constraints. Developing a continuous, efficient process becomes complex when technologies are misaligned, when upstream solutions generate outputs unfit for downstream needs, or when certain steps — especially those dealing with sorting or fiber regeneration — are simply not yet designed for textile use cases. The textile waste stream, unlike many others, is **non-standardized, variable, and often lacks clear classification** — making both sorting and recycling unpredictable and hard to optimize.

In this sense, the value of mapping technologies is not only to know what exists, but to understand what is **missing**: where scalability is not yet possible, where costs are too high, where quality is not consistent, and where knowledge is still fragmented. These gaps are not only technical; they are strategic signals, showing where innovation, regulation, and industrial collaboration need to focus. They also speak directly to the challenge of decision-making: *Given a specific stream of sorted textile waste — what can be done with it? What can't be done, and why?*

By linking existing technological efforts to practical transformation pathways, this chapter aims to provide a grounded framework for stakeholders — recyclers, designers, manufacturers, policymakers — to navigate the complexity of textile recycling today. Because understanding what technologies are available is only the beginning. The deeper task is to reveal what remains to be built — and how.

4.1 Landscape of Textile Recycling Technologies and Actors

As part of the technology assessment carried out for this report, we conducted a structured mapping of companies, research groups, technology providers, and industrial associations that are actively contributing to the development and application of textile recycling technologies. This mapping focuses on actors operating at different stages of the value chain and includes both experimental initiatives and consolidated industrial solutions.

The results are presented in this chapter as a synthesis, while the full detailed report — included as an annex (Annex 2) — can stand on its own as an independent resource, offering an in-depth look at specific technologies, actors, and innovation trends.

Thus, the assessment consists of three complementary outputs:

1. **A detailed technical report**, providing qualitative insight into the technologies, projects, and innovation trajectories of selected actors (Annex 2).
2. **A Matrix of Recycling Technologies**, organizing companies by role, technological focus, readiness level (TRL), country of origin, and other metadata (" available as an Excel file").
3. **A summarized actor map**, presented in the following, that categorizes the ecosystem of initiatives across key functional areas.

Together, these tools offer a foundational view of the current state of innovation in textile recycling, highlighting not only what technologies are emerging, but also where gaps remain and which actors are shaping the transition.

4.1.1 Methodological Approach

The objective of this investigation was to identify, analyze, and categorize technologies currently available, both consolidated and experimental/project-based, across the European textile recycling value chain. The focus was placed specifically on collection systems, material sorting, and mechanical and chemical recycling processes, with particular attention to actors operating in the wool and animal fiber recycling sectors.

The assessment followed a **qualitative and comparative approach**, structured across multiple phases:

Extensive desk research, conducted on:

- Academic publications and online resources
- Industry reports and market analyses
- Technical data sheets and publicly available corporate presentations
- Patent databases and scientific articles on emerging technologies
- Materials collected from trade fairs and sector-specific exhibitions

Technology mapping, based on:

- **Type of material** processed (with focus on wool, cotton, polyester, and blended fabrics)
- **Type of treatment** (collection, sorting, mechanical recycling, chemical recycling, or hybrid processes)
- **Level of technological maturity** (TRL), distinguishing between consolidated, experimental, or pilot-phase technologies

- **Degree of automation** involved in each process step

Field investigation conducted in two key Italian textile regions — **Piedmont and Tuscany** — which included:

- Structured qualitative interviews with professionals working in regeneration, sorting, and waste treatment
- On-site visits to selected industrial facilities, enabling direct observation and critical assessment of technologies in real operational contexts

This methodology enabled the creation of:

- A **structured classification** of current and emerging recycling technologies
- A first identification of **systemic weaknesses**, such as insufficient automation for handling blended materials, and the **lack of institutional support frameworks**, such as consortia or certification bodies dedicated to textile recycling

4.2 Actors and Their Roles Across the Value Chain

Hubs, Consortiums, and Associations

Organizations fostering collaboration, experimentation, policy coordination, and knowledge sharing on textile waste valorization.

- **ASTRI – Italian Recycled Textile Association**
- **Como Textile Waste Hub**
- **Corertex – Textile Reuse and Recycling Consortium**
- **Magnolab**
- **Retex Green**
- **Rreuse**

Technology and Machinery Developers

Companies and groups building technologies for sorting and recycling, ranging from early-stage innovations to market-ready systems.

Sorting-focused:

- **Pellenc ST** – Optical systems for composition and color separation
- **Picvisa** – Optical/AI-based textile sorting
- **TOMRA Recycling** – NIR/VIS spectrometry with preprocessing (e.g., removing zippers)

Recycling-focused:

- **ANDRITZ** – Full recycling lines (fiber prep, shredding)
- **Carbios** – Enzymatic PET recycling
- **Casati Flock & Fibers** – High-quality flock from waste
- **Erema** – FibrePro:IV for PET-to-PET recycling
- **Ommi** – Patented mechanical defibering
- **Recyc'Elit** – Selective chemical recycling of polyester

- **Re-Sport** – Specialized in complex post-consumer equipment

Manufacturing Companies Using or Integrating Recycling Technologies

Industrial actors that apply or integrate recycling technologies into their manufacturing process or supply chain.

- **Alta West GmbH**
- **Boer Group**
- **Comistra**
- **DBT Fibre**
- **Evadam**
- **FCC Environment**
- **Green Line**
- **Insertega**
- **J Gomes**
- **Manteco**
- **Marchi & Fildi SpA**
- **Nouvelles Fibres Textiles**
- **Recover Textile Systems**
- **Romeo Carlesi – Textile Raw Materials**
- **Soex**
- **Texaid**

Hybrid Innovators (Techologies + Manufacturing)

Companies combining technology development and recycling-based manufacturing, often producing regenerated fibers or pigments.

- **Circulose** – Produces CIRCULOSE® from recycled cotton waste
- **Infinited Fiber** – Converts waste into new high-quality fibers
- **Techna Italia / Officina +39** – Recycrom™ pigment from waste
- **Worn Again Technologies** – Chemically recycles blended materials

Company	Developed Technologies
ANDRITZ	Comprehensive textile recycling lines and machinery for fiber preparation, shredding.
Borsoi	Down and fiber recovery systems from padded items; customized recycling solutions. Customized recycling projects.
Carbios	Enzymatic recycling of PET-based fibers, breaking them down into base monomers.
Casati Flock & Fibers	High-quality flock powder production from textile waste for industrial use.
Circulose	Production of CIRCULOSE® from recycled cotton and production waste for circular fashion.
Erema	INTAREMA® FibrePro:IV system for PET fiber-to-fiber recycling with spin lubricants removal.
Infinited Fiber	Technology converting textile waste into new soft, high-quality fibers for diverse textile applications.
Ommi	Mechanical textile recycling through patented defibering technology for post-industrial and post-consumer waste.
Pellenc ST	Advanced optical sorting systems for composition and color-based separation of textiles.
Picvisa	Automated textile sorting using optical sensors, IR and AI for material and color identification.
Recyc'ELIT	Patented chemical recycling process for polyester-based textiles, enabling selective material separation.
Re-Sport	Recycling technologies for complex sports equipment and daily-use items.
Techna Italia / Officina +39	Recycrom™ technology for pigment production from used garments and production waste.
TOMRA Recycling	Automated textile sorting using NIR/VIS spectrometry, including pre-processing to remove zippers and buttons.
Worn Again Technologies	Chemical recycling of blended textiles into base materials (cellulose, PET), removing dyes and contaminants.

Table 9: Main recycling technologies innovators

As part of the technology mapping, all identified actors involved in textile recycling technologies have been categorized by country of origin. This geographic breakdown offers a preliminary view of how innovation capacity and industrial engagement are distributed across Europe and beyond.

Total Companies for Country	N°	%
	47	100%
Austria	2	4%
Belgium	2	4%
EU	1	2%
Finland	2	4%
France	5	11%
Germany	4	9%
Italia	19	40%
Netherlands	1	2%
Portugal	1	2%
Spain	4	9%
Sweden	3	6%
UK	2	4%
Swiss	1	2%

Table 10: Countries map

Companies identified in the mapping often engage in more than one type of activity along the textile recycling value chain. As a result, the percentage breakdown by activity reflects overlapping roles, and the sum of individual categories exceeds 100%.

Voices	Phases of Textile Waste Management	Technology	%
	Identified Companies		100%
Services	Business, Consulting, Support		23%
	R&D		36%
	Awareness, Education		26%
	Certification		2%
	Hubs, Consortiums, Associations		15%
Technology. Machinery producers	Manufacturing		40%
	Technologies for textile recycling	Consolidated	15%
		Experimental/Projects	13%
		Manufacturing	9%
Technology and machinery users	Collection, Selection/Sorting	Sorting Industrial Waste/Pre-consumer	45%
		Sorting Post-consumer	60%
		Automated Sorting Systems	32%
		Manual Sorting / Assisted by AI	28%
		Sorting by Composition	23%
		Sorting by Color	26%
		Supplier of Selected Waste	13%
		Reuse or Recycling	17%
	Materials Recycling, Transformation	Mechanical – Shredding	40%
		Thermomechanical	4%
		Pulverization	4%
		Enzymatic	2%
		Chemical Dissolution	32%
Final product	Yarn	Spinning	21%
	Fabric/Garment		4%
	Non-Textile Industries		9%

Table 11: Identification of recycling activities

From the above table you can appreciate the most widespread activities and the most lacking ones.

The analysis of the mapped actors reveals several important patterns:

- **Italy is the leading geography**, accounting for 40% of the companies identified, underlining its central role in textile recycling innovation.
- **Post-consumer sorting is the most addressed phase** (60%), with both automated (32%) and AI-assisted manual systems (28%) being developed, but most are still fragmented or in pilot phase.
- **Chemical recycling** is one of the most advanced but still underrepresented segments: only 32% of actors are working on it, and few have reached industrial maturity.
- **Innovations in pulverization, enzymatic and thermomechanical recycling** are limited (<10%), suggesting these are priority areas for future R&D investment.
- **End-of-chain reintegration (e.g., yarn or fabric production)** remains weakly covered: only 21% of mapped actors are involved in spinning, and even fewer in fabric manufacturing or non-textile applications.

These patterns highlight the asymmetry between the front-end (collection/sorting) and the back-end (transformation into new materials) of the textile recycling chain.

4.3 Strategic insight of the technology assessment

The current landscape of textile recycling technologies is rich in experimentation but still lacks full-system integration. Many technologies operate in silos: sorting systems may not be compatible with downstream recyclers, or regenerated materials may not meet quality standards for reuse in high-end applications. Moreover, many companies still operate at pilot scale or in closed loops, without broader system interoperability.

This fragmentation reflects broader structural challenges:

- Technologies across the chain often have mismatched TRLs
- Sorting and recycling systems are not always designed for textile-specific needs
- Lack of standardization and material traceability increases uncertainty
- Few actors are focused on reintegration of recycled materials into competitive products

Understanding these disconnects is crucial. It allows stakeholders — from manufacturers to policymakers — to identify where innovation, investment, and cross-sectoral collaboration are most urgently needed. This mapping, while not exhaustive, offers a foundation for that reflection and a basis for further, more detailed sector-wide assessments.

5. Circularity Scoring for Textile Waste: Multi-level model and Recyclability Indices developed in the Italy GreenTex Hub

As mentioned above, developing an Index for recyclability of textile waste is a pivotal objective for the current research: the scoring of the index would guide textile waste families toward the most suitable and economically or technically viable end-use applications, enhancing the efficiency and effectiveness of circular textile flows.

In the exploration of the state of the art, very few research efforts have been dedicated to developing a structured and universally applicable index of recyclability for Textile waste materials. While other sectors (plastics, metals, vehicles) have long developed recyclability metrics, textiles have lacked a comprehensive, systematic method to assess and compare the potential of waste materials to be re-integrated, after transformation processes, into new applications.

The lack of similar studies, probably also due to the complexity of textile waste, highlights a critical gap in the academic and industrial understanding of how to systematically evaluate and quantify the recyclability of textile waste to be exploited in new products.

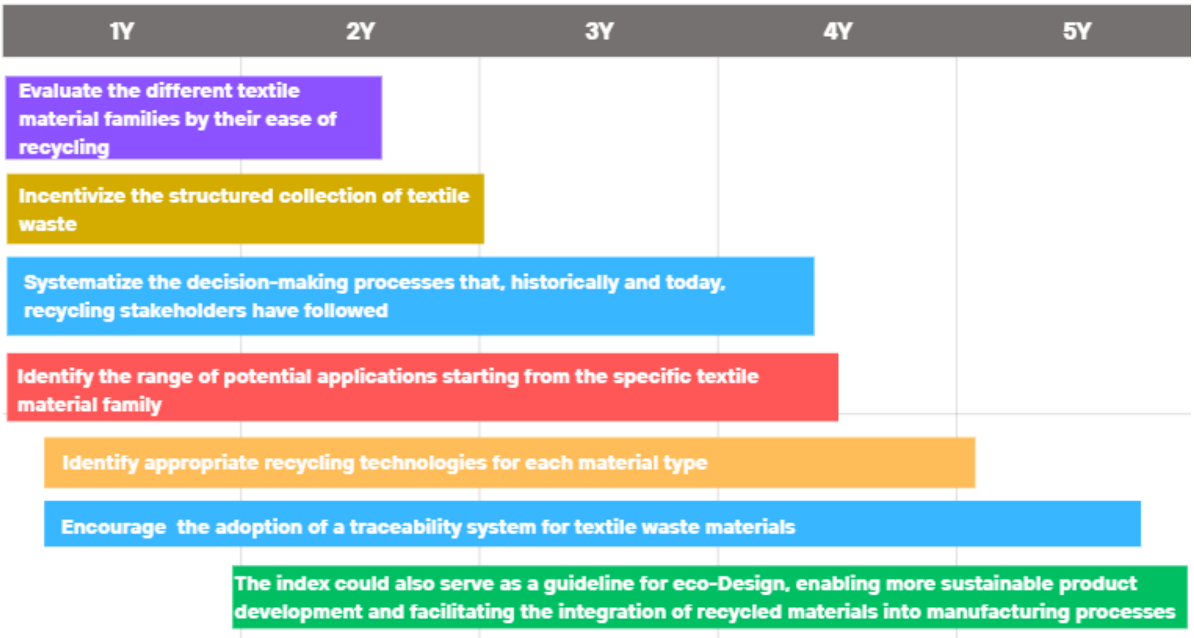
This chapter aims to bridge that void by introducing a preliminary methodology (TIOR) to evaluate sorted textile material families and complements it with two additional potential frameworks: TERI, focused on economic viability and TRI, which targets recyclability from the earliest stages of product design.

Grounded in insights gathered from industry experts during interviews and supported by existing standards and certifications, the proposed index named **TIOR – Textiles Index of recyclability** is based on a synthesis of a set of 15 measures - or observations - on textile waste material analysed and their expression in different categories of potential final applications where the waste could be used for. These measures include fiber properties, contaminants, certifications and application relevance, which are identified as *key parameters (KPx)* for assessing the recyclability of the textile material flow analysed.

The goal is to provide a robust tool for stakeholders across the value chain - from recyclers, sorters to designers - to make informed decisions, optimize processes and enhance and increase the integration of recycled textile materials into new products.

The specific objectives for the creation of a similar index are:

- Evaluate the different textile material families by their ease of recycling (Short-term objective)
- Incentivize the structured collection of textile waste (Short-term)
- Systematize the decision-making processes that, historically and today, recycling stakeholders have followed along the value chain to incorporate textile waste into new products (Medium-term)
- Identify the range of potential applications starting from the specific textile material family (Medium-term)
- Identify appropriate recycling technologies for each material type (Medium/Long-term)
- Encourage the adoption of a traceability system for textile waste materials (Medium/Long-term)
- The index could also serve as a guideline for eco-Design, enabling more sustainable product development and facilitating the integration of recycled materials into manufacturing processes (Medium/Long-term)



During the development of this index, additional proposals emerged for evaluating recyclability of materials at different stages of the textile value chain as detailed in the following sections presenting the TERI and TRI indices:

- **TERI - Textile Economic Recyclability Index**: a filter to evaluate the economic viability of recycling.
- **TRI - Textile Recyclability Index**: an exploratory idea aimed at assessing recyclability during product design.

5.1 The state of the art about the creation of an index of recyclability for Textile waste material

The development of an index of recyclability specifically tailored to textile waste materials remains a nascent field, with limited research and industrial applications to date. While recycling practices and frameworks have been established in other sectors - such as plastics or metals - the textile sector faces unique challenges due to the diversity and complexity of materials, blends and processing techniques. Current methodologies for assessing recyclability in textiles are often fragmented, focusing on isolated aspects such as fiber type, contamination levels, or environmental impact, rather than offering a holistic, multi-parameter approach.

While certain frameworks, like the GRS or RCS, have made strides in promoting traceability and certifying recycled content, they fall short of providing a comprehensive methodology to quantify recyclability. LCA studies further contribute by assessing the environmental impacts of textile recycling, but they do not directly evaluate the recyclability potential of materials. However, emerging studies and methodologies, both within textiles and other sectors, offer valuable insights into how an effective recyclability index could be developed.

Villalba et al. (2002): this seminal study defines recyclability as the ability of a material to reacquire the properties it had in its virgin state. The researchers propose a mathematical Recycling Index (R) based on the material's devaluation during its first use, as reflected by its loss of monetary value. By applying this concept to metals, which have advanced recycling technologies, the authors demonstrate how the index can provide a thermodynamic and economic benchmark for recyclability. While focused on metals, the framework offers a transferable approach for textiles, particularly in assessing the economic devaluation of fibers during recycling processes.

M.J. Glasper et al. (2021): this study introduces a recyclability index for post-consumer wool and cashmere fabrics based on fiber length retention during mechanical recycling. It highlights the challenges posed by natural variability in fibers and fabric structures and quantitatively analyzes how initial fiber length influences retained length and tensile strength after recycling. The authors propose a theoretical R-value that estimates the maximum number of recycling cycles a fabric can undergo before reaching the minimum spinnable fiber length of 20 mm. This approach, while specific to wool, establishes a methodology for evaluating mechanical recyclability across other fiber types.

Recyclability Potential Index (RPI) by Muthu et al. (2012): This study proposes a RPI for textile fibers, incorporating environmental and economic gains from recycling. It quantitatively evaluates the RPI of ten commonly used textile fibers, revealing that polyester and polypropylene have the highest potential for recycling, while nylon 66 has the lowest. By systematically analyzing the recyclability of fibers, this research highlights how environmental and economic factors can guide material choices and recycling strategies.

The development of recyclability indices in other industries provides valuable lessons for textiles:

- Recyclability Index for Automobiles (Tsuji et al.): this index evaluates the end-of-life recyclability of vehicles, combining factors such as the content of ferrous and non-ferrous metals (100% recyclable) and plastics with an established recycling market. The framework also incorporates a toxicity index to assess hazardous material content, providing a dual perspective on environmental impact and recyclability. This comprehensive approach offers parallels for textiles, where multi-material blends and hazardous chemicals also pose challenges.

- Rating Systems for End-of-Life Vehicles (ELV): an ELV rating system combines recyclability and toxicity metrics to quantify the environmental impacts of vehicles. The system has been proposed as a tool for educating consumers and incentivizing manufacturers to adopt eco-friendly designs. A similar system for textiles could motivate designers and manufacturers to prioritize recyclable materials and minimize chemical additives that hinder recycling.

These studies and methodologies highlight common themes that could guide the creation of a recyclability index for textiles:

- Economic Viability
- Material Properties
- Environmental Impact
- Multi-Parameter Frameworks

5.2 Proposed Methodology for TIOR: from intuition to structured evaluation

The development of an Index of Recyclability, as TIOR, is envisioned as a tool that replicates the decision-making process currently performed by textile recycling stakeholders, such as those operating within textile districts like Prato and Biella. Today, many of these decisions rely heavily on experience, intuition and sensory evaluation - touching the material, observing its composition and sometimes performing minimal tests to determine its potential applications. The index aims to bring structure, method and scalability to this process, offering a systematic framework that complements existing practices.

The usefulness of this tool is particularly evident after the **sorting phase** - which may include automated processes - has categorized and grouped textile waste into distinct material families based on their composition and color, as presented in the Chapter 3. At this stage, materials, whether post-industrial, pre-consumer or post-consumer are judged as "suitable" for recycling and compacted into bales for further processing. **The challenge then becomes determining the most appropriate end-use application for the families created, so that the textile material can be directed to the specific segment of the value chain that will enable the achievement of the final application with different processes of transformation.** One of the crucial objectives for the Italy GreenTex Hub.

We can imagine an experienced stakeholder from the textile industry standing before a flow of sorted material belonging to a specific family, as represented in the figure beside.

Using their expertise, they might rely on touch, sight and a handful of rapid tests to evaluate whether the textile material, already sorted in families, could be used for their specific application, often with a focus on high-quality **fiber-to-fiber recycling** in case of Prato and Biella actors.

The proposed index simulates this process by quantifying key parameters that such experts intuitively consider, offering a structured and objective method to evaluate the recyclability and application potential of the material.

Then, the TIOR is designed to address a critical gap in the decision-making landscape of textile recycling. Along the value chain, numerous decisions must be made and many tools are needed to support these choices. However, this index focuses specifically on the post-sorting phase, when materials have already been deemed suitable for recycling and according to different criteria (refer to section 3.4).

By providing stakeholders with an objective and data-driven method for assessing material recyclability, the index aims to:

- Support application decisions: help stakeholders identify which applications are best suited for a given material family.

- Enhance decision-making consistency: reduce reliance on subjective judgment by offering measurable parameters.
- Promote high-quality Fiber-to-Fiber Recycling: enable stakeholders to prioritize materials for applications requiring high-quality recycled fibers, aligning with circular economy goals. This operation requires the study of technological solutions with guidelines for F2F users.

By integrating technical, economic, and environmental considerations, the index serves as a bridge between traditional expertise and scalable, modern solutions. It does not aim to replace human intuition but rather to complement and enhance it, particularly in complex or large-scale operations where subjective decision-making alone may not suffice.

Another available decision-making tool, which differs from the TIOR but ideally complements it, operates during the **pre-sorting phase** (ref. Map of the Value chain in Section 2). At this stage, materials arriving from diverse origins are categorized based on their suitability for specific pathways, such as "reusable in other markets," "recyclable," "repairable" (or other 5Rs) or destined for landfill. For this purpose, the tool developed under the CISUTAC project, previously mentioned, serves as a robust solution for pre-sorting. Stakeholders are encouraged to explore this tool further, as it provides essential support for making informed decisions at this critical stage. More information about the CISUTAC tool can be found at the link: [https://www.cisutac.eu/solution-post-consumer-textile-waste].

While the pre-sorting tool focuses on categorizing materials broadly based on their initial condition and recovery potential, the TIoR is designed to take over in the subsequent stage. It evaluates recyclable materials in greater detail, assessing their suitability for specific applications and driving decisions, particularly in the context of high-quality fiber-to-fiber recycling.

Together, these tools create a complementary framework that supports the entire decision-making process in textile recycling, from initial sorting to application-specific assessment.
In the following, we report the methodologic steps adopted to generate the new index.

The methodology is structured around **six key stages**, each designed to build a robust and reliable index capable of guiding decision-making in recycling processes. It evaluates **15 Key Parameters (KP1–KP15)**, grouped under technical, economic and environmental dimensions.

A **seventh step**, focused on defining a logical sequence of parameter evaluation and potential economic pre-screening (e.g., through the TERI index), is currently under consideration as a next phase of development.

The methodology leads to the creation of an **overall recyclability index** for the analyzed family of textile material for recycling. This index provides a comprehensive assessment of **how recyclable the material is in general**, reflecting its suitability across different recycling processes and potential applications.

An important distinction emerges at **Step 4**, where an additional **application-specific recyclability index** is calculated. This index acts as a **subset or detailed component** of the overall recyclability index, as it focuses on measuring **how recyclable the material is for a specific application** (or macro-category of applications). This approach enables a targeted evaluation, allowing stakeholders to understand not only the general recyclability of the material but also its optimal uses within defined sectors such as apparel, automotive, or technical applications.

By combining these two levels of assessment, the methodology provides a powerful decision-making tool for identifying the best recycling strategies and end-use applications for different families of textile materials.

1.Define Key Parameters

The foundation of the TIOR lies in the identification of key parameters that influence the recyclability of textile materials. These parameters are designed to capture the technical, economic and environmental dimensions of recyclability, ensuring a comprehensive and balanced approach to evaluating and enhancing the circular potential of recycled textiles.

It is beyond the scope of this work to comprehensively include all factors that could influence the recyclability potential of textile materials. Instead, this report represents an initial attempt to establish a structured foundation for developing a robust recyclability index. By grounding the framework in **technical**, **economic**, and **environmental** parameters, we aim to ensure that the index reflects the diverse and interdependent considerations that shape (or must shape) decision-making in the textile recycling process.

Covering all perspectives is essential:

- Technical feasibility: understanding the physical and chemical properties of materials (e.g. fiber length, contaminants) is crucial for identifying whether recycling technologies can process them effectively in line with the needs of the final applications.
- Environmental impact: recycling is often pursued to reduce resource consumption, emissions and waste. Evaluating the environmental benefits and costs (e.g., energy or water use during processing or carbon emissions) ensures that materials chosen for recycling genuinely contribute to sustainability goals.
- Economic viability: the economic dimension is equally critical. Even if a material is technically recyclable and offers environmental benefits, its recycling may not be justified if the costs outweigh the benefits. For instance, a textile waste flow may technically meet all criteria for a specific application, but if the process is too expensive, stakeholders may opt for virgin materials instead.

By evaluating the market value of textile waste material for recycling, the index enables the identification of high-value material families that warrant further investment in recycling infrastructure. This ensures that resources are allocated to materials with significant potential for profitability and market demand. The economic value of the material helps stakeholders prioritize textile waste that offer the best return on investment, bringing to support also the supply chain optimization by offering a clearer understanding of economic dynamics.

Focusing on all three perspectives is essential to reflect the real-world trade-offs faced by stakeholders in the textile value chain. For example:

- A recycled textile might require advanced sorting and processing technologies that increase costs, making it less competitive compared to virgin alternatives.
- Conversely, balancing economic factors with technical advancements and environmental benefits can drive innovation, incentivizing investment in more efficient recycling systems.

At this research stage, we have identified 15 key parameters (**KPx**), drawing insights from interviews and additional sources that analyse frameworks both for evaluating textile materials and references for assessing broader sustainability initiatives.

Based on the interviews, the following factors emerge as important for the recyclability such as:

1. Material homogeneity: Purity level or presence of contaminants (physical contaminants, e.g. labels, stitching).
2. Fiber length: Short or long fibers impact the quality and potential applications of

recycled material.

3. Available certifications: REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), GRS or OEKO-TEX® certification (their presence enhances traceability and compliance)
4. Material source: Differentiating between post-industrial, pre-consumer and post-consumer waste and/or Geographical distribution of different sources.
5. Color consistency: Homogeneity in color reduces the need for resource-intensive re-dyeing
6. Degree of blending: for the impact in the feasibility of recycling processes
7. Fiber Fineness: refers to the thickness of individual fibers, typically measured in microns. Finer fibers (e.g., $\leq$ 22-24 microns) are generally associated with higher-quality applications but may present challenges in mechanical recycling due to their fragility. Ordinary fibers (> 22-24 microns) are more robust and often more compatible with nonwoven or insulation applications.

We have integrated the parameters with insights from the literature. Additional parameters were identified through the tool developed within the framework of the CISUTAC project [Horizon Europe research and innovation programme, grant agreement No. 101060375].

The methodology also considers parameters that extend beyond material properties. For example, certifications like GRS (Global Recycled Standard) or REACH provide essential information about traceability and sustainability, while factors such as color consistency and fiber length influence the material's suitability for specific recycling technologies or applications. By clearly defining these parameters and their scoring ranges, the methodology establishes a solid framework for evaluating recyclability with precision and consistency.

We studied several potential parameters, particularly those derived from the Eco-design requirements outlined in the ESPR (Ecodesign for Sustainable Products Regulation). Although these requirements are primarily designed for final products, we propose that some of them could also be applied to the materials being used, as their properties influence how closely they align with eco-design principles. Among these, we specifically analyzed "durability", "upgradability" and "reliability", but found it challenging at this stage to incorporate them into the methodology due to the complexity of defining appropriate measurement criteria.

The final list of 15 KPs, validated for this stage of study, is reported below and, as mentioned, it results from individual studies and analyses conducted by the members involved in this research, combined with brainstorming sessions and validation meetings carried out during the early weeks of January 2025. This iterative approach ensured a comprehensive selection of parameters, reflecting both expert insights and collaborative refinement.

	Data source	Key Parameters (KPx)	Definition
KP1	Interviews	**Degree of Blending**	Indicates the extent to which different fiber types are blended within the material. Mono-fibers are preferred for recycling, while complex blends reduce recyclability.
KP2	Interviews	**Purity - Presence of physical contaminants**	Assesses the presence of physical contaminants that can hinder the recycling process and the quality of the textile material analysed. These contaminants include physical elements such as labels, zippers, buttons, or other attached components, as well as non-fibrous materials like vegetable matter, wood, or plastics (e.g. coffee cups) embedded within the textile. High purity, meaning minimal or no contaminants, results in better recycling outcomes, reducing the need for additional pre-processing and enhancing the efficiency of recycling technologies.
KP3	Interviews	**Homogeneity**	Evaluates the uniformity of the material composition. Fully homogeneous materials are easier to recycle compared to mixed or heterogeneous compositions.
KP4	Interviews	**Fiber length**	Refers to the average length of the fibers. Longer fibers (e.g. 70-80 mm or above) are generally more desirable for recycling than shorter fibers.
KP5	Experts	**Fiber Fineness**	Finer fibers are easier to process into high-quality recycled materials/products, while other fibers may be limited to applications like non-woven fabrics or industrial textiles (*Fiber count refers to the number of individual fibers that compose a single yarn cross-section*).
KP6	Interviews	**Certification**	Measures the presence and level (mandatory/voluntary) of recognized certifications applicable to the incoming material. Certifications ensure better traceability and sustainability throughout the supply chain. Importantly, certifications obtained at the material level can be carried forward and reflected in the final product, such as through compliance with standards like REACH.
KP7	Interviews	**Chemical Load and Ecotoxicity**	Evaluates the level of chemical residues in the material.
KP8	Interviews	**Source**	Refers to whether the material originates from post-industrial, pre-consumer, mixed, or post-consumer sources. Post-Industrial materials are typically easier to recycle.
KP9	Interviews	**Geographical source**	Indicates the origin of the material, which influences the quality and consistency of the incoming recycled material. Geographic origins can affect factors such as fiber contamination levels, previous treatments, and overall material condition due to differences in collection, sorting, and local processing standards. Local or EU sources may have higher traceability and quality control, leading to better recyclability outcomes. Additionally, for certain brands, materials originating from specific countries may be considered "undesirable" due to sustainability, ethical, or regulatory concerns, affecting their integration into production processes.
KP10	Interviews	**Colour consistency**	Refers to the uniformity of the material's color. Consistent coloring facilitates recycling processes, as it reduces the need for re-dyeing or additional color adjustments. When the color uniformity is optimal, it can eliminate or minimize the need for fiber dyeing processes, leading to significant savings in energy, water, and chemical use, and enhancing the overall sustainability of the recycling process. Conversely, heavy color variations may lower recyclability and require more intensive processing.
KP11	Experts	**Processability without further damage**	Measures the material's ability to undergo the necessary recycling processes without significant degradation in quality. Materials with high processability maintain their original fiber strength, length, and structural integrity throughout processing, ensuring they remain suitable for high-value applications. Conversely, materials prone to excessive damage or degradation during processing may see reduced recyclability and lower quality outputs.
KP12	Interviews	**Environmental Impacts**	Assesses the environmental footprint of the material, including emissions and resource use. Lower impacts result in higher scores.
KP13	Other	**Market value**	Measures the economic value assigned by the market to the waste material, reflecting its demand and desirability in various applications (e.g., premium wool versus low-grade polyester). Additionally, this parameter compares the recycled material's market value with the cost savings it offers relative to its virgin counterpart.
KP14	CISUTAC/Experts	**Degree of material degradation**	Refers to the apparent condition of the material, assessing signs of degradation, damage, or overuse. The degree of wear directly influences the quality of the recycled material after processing, affecting its strength, durability, and overall performance. Higher wear levels typically result in lower-quality recycled outputs and reduced market value, limiting the material's applicability in high-end products. Conversely, materials with minimal wear retain higher quality and are more desirable for fiber-to-fiber recycling or premium applications.
KP15	CISUTAC/Experts	**Fabric structure**	Refers to the physical configuration of the textile recycling material (e.g. knitted, warp and weft, non-woven). The structure affects how easily fibers can be separated and processed during recycling. Knitted fabrics generally have higher recyclability due to their better fiber separation and reduced mechanical stress. In contrast, tightly woven or highly compacted structures can damage fibers during processing, leading to shorter fibers, lower quality outputs, and limited applications for fiber-to-fiber recycling.

Table 12: 15 Key Parameters of the TIOR methodology for evaluating textile waste material for recycling

The selected parameters are intended to represent appropriate measurements taken after the sorting phase, ensuring that the waste material under evaluation belongs to a **well-defined family of textile waste materials**. In fact, all the criteria described in Section 3.4 for defining material families should ideally be measured during the previous and – potentially - iterative sorting stages.

During sorting, materials are classified based on key characteristics such as fiber composition, colour, forming homogeneous groups that facilitate downstream processing. This reiterative sorting approach is essential to gradually refine the categorization and improve the consistency of the material families. As a result, by the time the selected parameters are measured in the recyclability index, the material already meets the baseline criteria needed for reliable evaluation (composition and color for example).

This sequential, structured approach ensures that the recyclability index reflects not only the intrinsic properties of the material but also the efficacy of the preceding sorting and classification processes, ultimately enhancing the precision of the recycling assessment.

2. Definition of Scoring per range for each parameter

Once the parameters are defined, each is assigned a scoring range that reflects its impact on recyclability of the material analysed. The scoring system is designed to be intuitive and quantifiable, allowing for clear differentiation between materials. This step ensures that the index captures the nuances of waste material characteristics and aligns them with their recyclability potential.

Defining scoring ranges for each parameter is a critical step in the development of the recyclability index. While the ranges proposed in this methodology provide an initial framework, they are meant as a starting point for further refinement. The challenge lies in accurately calibrating these scores to reflect real-world recyclability potential, which requires a more rigorous, data-driven approach.

Ideally, scoring ranges should not simply rely on theoretical assumptions: they should be grounded in a mix and synthesis of expert inputs collection and empirical evidence. This would involve conducting technical interviews and extensive testing on a wide variety of textile materials to evaluate their behavior across different recycling processes. These tests could include, for example:

- Physical and chemical analyses to measure how fiber blending and contamination levels impact the efficiency and outcomes of recycling technologies.
- LCA to quantify environmental impacts, such as energy and resource savings when using recycled materials versus virgin onesEconomic studies to assess market demand, material value, and processing costs for different types of recycled textiles to be selected for a specific final application.

The data collected from these tests would then be used to refine and validate the scoring ranges. For example, fiber blends currently scored as “moderate recyclability” (e.g., 70/30 blends) might be adjusted if empirical evidence suggests they perform better, or worse, than anticipated under certain recycling conditions. Similarly, parameters like color consistency or chemical load could be scored more precisely once their actual impact on downstream applications and processes is quantified.

This iterative process of testing and data collection would allow the scoring ranges to evolve over time, ensuring they accurately represent the recyclability potential of various materials. Additionally, by relying on robust datasets, this approach enhances the credibility and applicability of the index across different stakeholders. Further details in the following sections.

	Key Parameters (KPx)	Scoring per range
KP1	**Degree of Blending**	Mono-material = 100
		Bi-blends = 80
		tri-blends = 50, higher blends = 20
KP2	**Purity - Presence of physical contaminants**	No contaminants = 100
		Macro contaminants (easier to detect and remove) = 50
		Micro contaminants = 10
KP3	**Homogeneity**	Fully homogeneous = 100
		moderately homogeneous = 70
		mixed = 40
KP4	**Fiber Length**	Long fibers (mm) = 90-100
		medium fibers (mm) = 70
		short fibers (mm) = 40
KP5	**Fiber Finess**	Fine fibers (<22 microns) = 90-100
		medium fibers (22-25 microns) = 70
		Ordinary fibers (>26 microns) = 40
KP6	**Certification**	Presence of REACH certification = 100
		presence of certifications other than REACH = 80
		no certification = 60
KP7	**Chemical Load and Ecotoxicity**	No chemicals detected = 100
		low levels = 80, moderate levels = 50
		high levels = 20
KP8	**Source**	Post-industrial= 90
		Mixed or pre-consumer = 70-80
		post-consumer = 50
KP9	**Geographical Source**	United states, EU, Switzerland, Australia, Japan = 90-100
		other regions = 50-70
		China or other undesirable sources = 40
KP10	**Color Consistency**	Uniform colors = 100
		minor variation = 70
		heavy variation = 30
KP11	**Processability without further Damage**	High = 100
		moderate = 70
		low = 50
KP12	**Environmental Impacts**	Low emissions and impact = 100
		moderate = 70
		high emissions = 30
KP13	**Market Value**	High value (e.g., premium wool) = 100
		medium = 70
		low value (e.g. short polyester fibers) = 30
KP14	**Degree of material degradation**	New or lightly used = 100
		moderately used = 70
		heavily used = 40-50
KP15	**Fabric structure**	Knitted = 100
		woven = 80-60
		non-wovens = 40 - 20

Table 13: Scoring defined for each Key parameter

3. Linking parameters to potential applications: definition of macro-categories of final applications based on textile recycled materials

Recyclability is not an isolated concept; it is closely tied to the potential applications of waste materials analysed.

Therefore, the methodology incorporates a classification system that enables the measurement of parameters specifically related to the final application (step 4) for which the recycled textile material under analysis is intended.

Then, an essential first step in this methodology has been to map the macro-categories of potential final applications for recycled textile materials. This mapping is fundamental to ensure that the recyclability index does not remain a theoretical exercise but is directly aligned with the practical needs and market opportunities of the textile industry.

By identifying these application categories, it becomes possible to create a structured framework that connects the intrinsic properties of recycled materials - captured by the key parameters - with the specific requirements of their intended uses. This step ensures that recycled textiles can be effectively directed toward the most suitable end-use applications, maximizing their utility and value within a circular economy framework.

The macro-categories identified can include the following list with refer to previous studies and research under similar thematics.

	Macro-categories of potential final application	Details
1	**Apparel and Fashion**	The apparel and fashion sector encompasses a wide range of products designed to combine aesthetics, functionality, and comfort. Within a circular economy framework, the use of recycled and regenerated materials is becoming increasingly important in reducing the environmental impact of the textile and fashion supply chain. Recycled textiles are used in everyday garments, technical clothing, linings, outerwear, and performance sportswear. At the same time, the footwear segment is also integrating sustainable materials, such as soles made from recycled rubber, uppers crafted from regenerated or bio-based fabrics, and components derived from industrial or post-consumer waste. These innovations not only support more responsible and circular fashion practices but also promote transparency and product durability throughout the entire lifecycle.
2	**Accessories and gadget**	The accessories and gadgets sector focuses on producing items such as bags, cases, promotional products, and home or office accessories. It values versatility, design, and functionality, with growing demand for sustainable and customizable options. Recycled textiles are used in *bags, covers, straps, promotional items, and decorative pieces*, offering lightweight, durable, and eco-friendly solutions with creative design potential.
3	**Cleaning and hygiene**	This sector covers products for industrial cleaning, personal hygiene, and medical protection. Recycled textiles are used in *industrial wipes, multipurpose cloths, and absorbent materials* for machinery and surface cleaning. Additionally, they are applied in disposable or reusable products such as *medical gowns, masks, protective covers, and sanitary wipes*.
4	**Building**	The building sector is a major driver for the use of recycled textile materials, offering diverse opportunities primarily in insulation systems. Products made from textile waste provide thermal and acoustic insulation, aligning with growing sustainability demands in construction. *Thermal Insulation* *Acoustic Insulation* *Fireproof and Treated Solutions*
5	**Infrastructure**	The infrastructure sector involves the construction and maintenance of essential public works such as roads, bridges, railways, airports, water systems, and energy networks. Non-woven fabrics made from pre- and post-consumer textile waste have become key to enhancing soil stability, drainage, and mechanical strength, supporting the construction of long-lasting infrastructure. *Geotextiles for groud reinforcement* *Reinforcement Asphalt*
6	**Furniture and interior (including Home textiles)**	The furniture and interior sector focuses on designing and producing furnishings, decor, and interior materials for residential, commercial, and public spaces. It emphasizes comfort, aesthetics, and functionality, with growing demand for sustainable solutions. Recycled textiles are used in *upholstery, padding, acoustic panels, carpets, and decorative items*, *Bed linens, pillowcases, blankets, and comforters*. *Curtains, upholstery fabrics, and carpets*.
7	**Automotive and Transportation**	The automotive and transportation sector covers vehicles and transport systems, including cars, buses, trains, and planes. It prioritizes performance, safety, and comfort. Recycled textiles are applied in *seating, upholstery, insulation, carpets, door panels, and soundproofing materials*, offering lightweight, durable, and eco-friendly alternatives that enhance acoustic and thermal performance
8	**Packaging**	This sector involves creating materials for wrapping and transporting goods, emphasizing protection, design, and sustainability. Recycled textiles are used in *reusable bags, protective wraps, and pouches*.
9	**Footwear**	The footwear sector focuses on the design and production of shoes for various uses, including fashion, sports, and workwear. It emphasizes durability, comfort, and design. Recycled textiles are used in uppers, linings, insoles, and padding, providing breathable, lightweight, and eco-friendly alternatives without compromising performance or aesthetics.
10	**Floricolture and gardening**	The sector covers plants, flowers, and related gardening materials. Recycled textiles are applied in *plant mats, weed barriers, geotextile fabrics, and pot linings*, providing breathability, water management.
11	**Household devices**	This sector focuses on products used in daily home activities and appliances. Recycled textiles are integrated into *filters, covers, padding*.

Table 14: Macro-categories of potential final applications based on textile recycled materials

While the macro-categories defined above represent the current framework, this mapping is undoubtedly a **work in progress and will evolve over time**. The final applications of recycled textile materials are at the heart of strategic studies aimed at steering textile waste away from incineration and toward integration into new products. As understanding of the market and technological capabilities deepens, these categories will likely be refined to better reflect emerging opportunities and ensure that recycled textiles contribute effectively to the circular economy.

In future studies, it will be essential to establish **expert panels for each potential sector** capable of absorbing recycled textile materials. These multidisciplinary groups can help to **break down the macro-applications into specific uses within subsystems and/or final products**. This detailed mapping will allow for a more granular understanding of viable applications—a range that is expected to expand and update year after year, unlocking new and increasingly diversified outlets for recycled textiles.

Recyclability as a Function of Application Potential

Recyclability is not an isolated concept but deeply interwoven with the potential applications of recycled materials. Insights from the textile industry interviews underscore that the end-use application directly influences how materials are selected, processed and ultimately valued. Below are key points derived from stakeholder discussions:

Material characteristics are tailored to applications

Interviews highlighted that material properties such as fiber length, composition, and purity often determine the feasibility of specific applications. For example:

- Short Fibers: Preferred for non-woven products like insulation or sound-absorbing panels due to their inability to be re-spun.
- Long Fibers: Reserved for spinning and weaving, essential for high-value garments or home textiles.
- Blended Fibers: Depending on the blend, materials like wool-polyester are redirected toward technical applications or low-value products.

Impact of contaminants and traceability

The presence of contaminants such as synthetic labels, zippers, or residual dyes affects recyclability but is acceptable in certain sectors like automotive or construction. In contrast, fashion and apparel demand cleaner, more consistent materials. The lack of robust data and traceability systems complicates aligning recycled materials with their intended applications.

Certifications guide applicability

Certifications like GRS or OEKO-TEX® often validate recycled materials for specific uses, ensuring compliance with safety, environmental, and performance standards. For instance, materials certified under REACH are more likely to be used in consumer-facing products due to regulatory assurances.

Market demand drives recycling pathways

Stakeholders noted that the marketability of recycled textiles hinges on aligning their properties with current demand. For instance:

- Automotive and insulation industries prioritize durability and cost-efficiency over aesthetic attributes.
- The fashion industry seeks color consistency and fiber softness, which may necessitate blending with virgin fibers to meet design standards.

Knowledge gap limits application

Many interviewees, especially from third-party processing companies, admitted a lack of awareness about the material families they handle. This knowledge gap limits their ability to optimize materials for diverse applications and underscores the importance of education and standardization.

Technological constraints

Current recycling technologies influence which applications are feasible. For example: Mechanical recycling often limits fibers to short lengths, restricting use to non-woven products.Advanced processes like chemical recycling can produce fibers suitable for high-end garments, expanding application potential.

Economic implications

Recycled materials destined for higher-value applications often fetch better prices, incentivizing their collection and segregation. Conversely, materials without a clear application may end up as waste despite their theoretical recyclability.

4.Define an application-based scoring assigning weighted scores to each parameter relating to each final application

The methodology goes a step further by assigning **weighted importance to each parameter based on its relevance to specific applications**. This ensures that the recyclability index is not only comprehensive but also adaptable to the diverse needs of the textile industry.

This step is essential to the success of the recyclability index, as it enables the evaluation of how recyclable a given family of textile materials is in relation to a particular application category (as defined in Step 3). By weighting the key parameters according to their importance for each application, the methodology **provides a nuanced and application-specific recyclability score**, rather than a generic evaluation. For example:

- Fiber Length: highly relevant for yarn production, where longer fibers contribute to better-quality yarn, but less critical for non-woven applications, where short fibers can still be effectively used.
- Purity – Physical Contaminants: crucial for high-value applications like fashion textiles, where even minor contaminants can disrupt the recycling process and reduce product quality.

The weights assigned to each parameter by experts were given according to the following predefined scale:

- **0** – The parameter holds **no relevance** for this application.
- **25** – **Low relevance**: the parameter has a **limited or secondary impact** and is only considered in specific cases.
- **50** – **Moderate relevance**: the parameter has a **modest influence** on the success of the final product.
- **75** – **High relevance**: the parameter is **important and significantly contributes** to the success of the application.
- **100** – **Maximum relevance**: the parameter is **critical and essential** for the feasibility or effectiveness of the application.

This step is both iterative and collaborative. Each weight can be refined and adjusted to better reflect its real-world importance for the application under consideration by involving domain-specific experts and/or conducting iterative feedback loops. Such refinement ensures that the weights are aligned with the technical, environmental, and economic realities of the industry.

In the current stage, we present a table that summarizes the **weights assigned by various expert teams** who studied the relevance of each parameter for specific applications.

The final weights have been calculated using the **arithmetic mean** of the values assigned by these teams. Where significant variance was observed between the assigned weights, we conducted follow-up consultations with the experts to understand the reasons for the discrepancies and adjust the values where appropriate.

This careful approach ensures that the scoring system is robust, reflective of expert consensus, and practical for use across different sectors (further details in Chapter 3.2.2).

	Key Parameters (KPx)/Applications	Application 1: Apparel and Fashion	Application 2: Accessories and gadgets	Application 3: Cleaning and hygiene	Application 4: Building	Application 5: Infrastructure	Application 6: Furniture and interior	Application 7: Automotive	Application 8: Packaging	Application 9: Footwear	Application 10: Floriculture and gardening	Application 11: Household devices
KP1	**Degree of Blending**	100	43,75	68,75	56,25	37,5	25	87,5	50	75	75	43,75
KP2	**Purity - Presence of physical contaminants**	87,5	56,25	93,75	50	25	56,25	75	50	81,25	87,5	50
KP3	**Homogeneity**	100	56,25	87,5	43,75	43,75	37,5	81,25	50	50	50	31,25
KP4	**Fiber Length**	81,25	37,5	37,5	37,5	43,75	37,5	68,75	43,75	68,75	25	18,75
KP5	**Fiber Count**	68,75	62,5	50	31,25	31,25	43,75	68,75	43,75	56,25	18,75	6,25
KP6	**Certification**	93,75	56,25	81,25	93,75	68,75	81,25	93,75	81,25	75	56,25	43,75
KP7	**Chemical Load and Ecotoxicity**	93,75	87,5	93,75	93,75	75	93,75	87,5	87,5	81,25	87,5	62,5
KP8	**Source**	100	81,25	81,25	50	37,5	37,5	62,5	25	62,5	43,75	50
KP9	**Geographical Source**	87,5	87,5	75	68,75	68,75	50	81,25	81,25	62,5	68,75	50
KP10	**Color Consistency**	100	75	50	25	12,5	56,25	68,75	37,5	56,25	6,25	18,75
KP11	**Processability without further Damage**	100	75	81,25	31,25	25	56,25	68,75	56,25	68,75	37,5	25
KP12	**Environmental Impacts**	87,5	56,25	62,5	62,5	68,75	50	93,75	56,25	62,5	62,5	43,75
KP13	**Market Value**	93,75	75	56,25	56,25	75	62,5	75	81,25	75	56,25	62,5
KP14	**Degree of material degradation**	100	56,25	62,5	31,25	50	56,25	68,75	62,5	43,75	50	31,25
KP15	**Fabric structure**	81,25	50	62,5	18,75	37,5	31,25	75	50	62,5	31,25	25

Table 15: Weights assigned to each parameter across different applications

After presenting the table, it is important to highlight that at this point, the **additional application-specific recyclability index can be calculated**.

$$\text{TIOR}_{\text{application-specific}} = \frac{\sum (\text{score x weight})}{\sum (\text{weights})}$$

This index acts as a subset or detailed component of the overall recyclability index, as it specifically measures how recyclable the material is for a given application or macro-category of applications. By combining the scores of the key parameters with their assigned weights for the specific application, this index provides a targeted evaluation.

This approach allows stakeholders to understand not only the general recyclability of the material but also its optimal use across different application sectors, such as apparel, automotive, packaging or technical textiles. As a result, this targeted recyclability index becomes an essential decision-making tool for identifying the most suitable applications for each material family, improving material flow allocation, and supporting strategic investments in recycling technologies.

It is important to note that this step can be **revised and improved over time**, both in terms of the weighting scale itself and the method used to link parameters to applications. For example, a possible refinement could involve duplicating each macro-category of application to differentiate between aesthetic applications (where materials are in direct contact with the end-user) and functional or technical applications (where performance is prioritized over appearance). Such an approach would allow for an even more granular and precise assessment of recyclability based on the specific requirements of the end-use sector.

As described in the previous step, the definition of the weight for each key parameter must be guided by application-specific expert panels. These multidisciplinary expert groups will be necessary for each application area to ensure that the weightings reflect real-world technical and market requirements. Furthermore, it is likely that these expert discussions will identify new key parameters beyond the current set of 15, as specific use cases may highlight additional factors relevant to recyclability, such as flame retardancy, biodegradability, or moisture resistance.

To better illustrate how this method works in practice, the following pages present **hypothetical but realistic examples of how the recyclability index would be calculated for specific applications** such as Apparel and Fashion and Floriculture and Gardening, using plausible recycled textile materials.

Example: TIOR for application – Apparel and Fashion

The waste material analyzed has been sorted as a family **bi-blend**, composed of **80% wool and 20% polyester**, derived from **post-consumer textiles** and sorted also for **light grey uniform coloration**. The qualitative assessment reveals:

- No physical contaminants (clean fabric)
- Moderately homogeneous structure (wool-polyester blend)
- Medium fiber length
- Fine fibers (21 microns)
- REACH-certified
- Low chemical load
- Post-consumer origin
- European source
- Uniform color
- High processability (handles well during mechanical recycling)
- Moderate environmental impact
- Medium market value (recycled wool has demand, but lower than virgin)
- Moderately used (light wear)
- Knitted fabric structure

The following table summarizes the individual scores assigned to each of the 15 key parameters (KPx), based on the observed characteristics of the analyzed material (Step 2 of the TIOR methodology) . These scores reflect the material's performance with respect to recyclability criteria.

Key Parameter (KP)	Observation	Score
KP1 – Degree of Blending	Bi-blend	80
KP2 – Purity	No contaminants	100
KP3 – Homogeneity	Moderately homogeneous	70
KP4 – Fiber Length	Medium	70
KP5 – Fiber Count	Fine fibers	100
KP6 – Certification	REACH	100
KP7 – Chemical Load	Low	80
KP8 – Source	Post-consumer	50
KP9 – Geographical Source	EU	100
KP10 – Color Consistency	Uniform color	100
KP11 – Processability	High	100
KP12 – Environmental Impacts	Moderate	70
KP13 – Market Value	Medium	70
KP14 – Degree of Degradation	Moderately used	70
KP15 – Fabric Structure	Knitted	100

Table 16: Score assignment based on waste material properties

For this example, the chosen application is **Apparel and Fashion**, a sector where both performance and aesthetics play a critical role in determining the suitability of recycled materials. *"The industry is increasingly under pressure to integrate circular strategies, particularly through the reuse of high-quality fibers such as wool".*

The table below presents the weighting factors associated with each key parameter for the selected application along with the calculated weighted scores (step 4). These values are obtained by multiplying each parameter's score by its application-specific weight, providing the basis for computing the final recyclability index through a weighted average approach.

KP	Weight (%)	Score	Weighted Score
KP1	100	80	8000
KP2	87.5	100	8750
KP3	100	70	7000
KP4	81.25	70	5687.5
KP5	68.75	100	6875
KP6	93.75	100	9375
KP7	93.75	80	7500
KP8	100	50	5000
KP9	87.5	100	8750
KP10	100	100	10000
KP11	100	100	10000
KP12	87.5	70	6125
KP13	93.75	70	6562.5
KP14	100	70	7000
KP15	81.25	100	8125
	Total weight = 1275		*Sum = 114750*

Table 17: Weighting for Application Apparel and Fashion

Based on the sum of all weighted scores and the total of the corresponding application-specific weights, the final recyclability index for the selected application is calculated as a weighted average. This value reflects the overall suitability of the material for use in the **Apparel and Fashion** sector, integrating both technical attributes and sector-specific priorities.

$$\mathbf{TIoR}\ \mathit{Apparel\&Fashion} = \frac{114.750}{1.275} = 90$$

The Recyclability Index for the "Apparel and Fashion" application is 90/100.

This high score confirms the material's strong potential for circular textile applications in fashion, thanks to its high purity, fine fibers, excellent processability, and supportive certification.

5. Define an application multiplier to adjust the final index for specific applications

It is possible to introduce an application multiplier that scales the "base recyclability score" up or down depending on how well the material's properties align with the needs of the specific application.

- If the parameters are highly suitable for the application (e.g., meets all key criteria), the multiplier increases the score (e.g., 1.2).
- If the parameters are moderately suitable (e.g., meets some but not all criteria), the multiplier is neutral (e.g., 1.0).
- If the parameters are less suitable, the multiplier decreases the score (e.g., 0.8).

The application multiplier adds a dynamic layer to the recyclability index, ensuring that the scoring reflects not only the inherent properties of the material but also its practical suitability for specific end uses. This approach creates a more actionable and industry-relevant metric.

6. Final scoring and classification

$$\text{TIOR} = m \times \frac{\sum (\text{score} \times \text{weight})}{\sum (\text{weights})}$$

The final step integrates all parameter scores, weights and application multipliers into a **composite and overall recyclability index**. Recycled Materials could be then classified into three categories:

- High Recyclability: Indicative of materials that are easy to recycle and suitable for multiple applications (score ≥75).
- Moderate Recyclability: Materials with some recycling challenges but viable for specific uses (score 50–74).
- Low Recyclability: Difficult-to-recycle materials that may require further innovation or alternative approaches (score <50).

5.2.1 Future integration in the TIOR methodology: Decision Tree approach for KPs sequencing and economic filtering

While the current methodology focuses on evaluating material recyclability through a weighted, multi-parameter approach, future developments may include an additional step aimed at defining a logical order of evaluation among the parameters. In constructing a recyclability index, understanding whether a logical order exists - or should exist - when measuring parameters is crucial. This logical sequence ensures that parameters are assessed systematically, building on foundational insights to inform subsequent evaluations.

The approach avoids redundancy, reduces errors and aligns the evaluation with real-world recycling processes, where certain material characteristics dictate the feasibility of downstream steps.

Why a Logical Order Matters

1. *Interdependencies between parameters:* Certain parameters (e.g., material composition) are foundational, as they influence the relevance of others (e.g., fiber length or blending degree). Assessing these first provides a clearer context for subsequent evaluations.

2. *Optimization of resources*: Prioritizing essential parameters can streamline testing and data collection, avoiding unnecessary evaluations for materials that fail key recyclability criteria early on. This is particularly relevant in a potential fine-tuning phase of the methodology, where a stop-measurement step could be introduced. At this stage, certain parameters could act as pass/fail checkpoints, determining whether it is worth continuing the assessment based on the material's suitability for a specific application. For instance:

3. *Alignment with recycling processes:* The order reflects the typical sequence in recycling workflows, such as sorting, pre-treatment, and processing, ensuring the index mirrors practical realities. In this context, a decision-tree logic could be introduced to structure the assessment process based on the relative importance of the parameters. The idea is to establish a hierarchical sequence of parameters, where each functions as a **cut-off point**: if a material does not meet a defined threshold at a certain stage - such as excessive blending or inadequate fiber length - the evaluation process can be stopped early. This avoids investing time and resources in assessing parameters that are no longer relevant once key criteria are unmet.

- A material that fails on composition (e.g., a highly complex blend) or has significant contamination might be deemed unsuitable for certain applications and excluded from further analysis.

- Conversely, materials passing these critical parameters could proceed to a more detailed evaluation, ensuring that resources and efforts are focused only on viable candidates.

  This approach not only prevents resource wastage but also ensures that the methodology remains practical and aligned with real-world industry needs, where some materials are inherently incompatible with certain applications. The pass/fail mechanism adds a layer of efficiency to the recyclability assessment, enabling targeted decision-making and prioritization.

In parallel, the **TERI (Textile Economic Recyclability Index)** could be implemented as a **preliminary economic screening tool**. By comparing the estimated recycling process costs to the market price of virgin raw materials, TERI helps determine whether recycling a given material stream is economically viable.

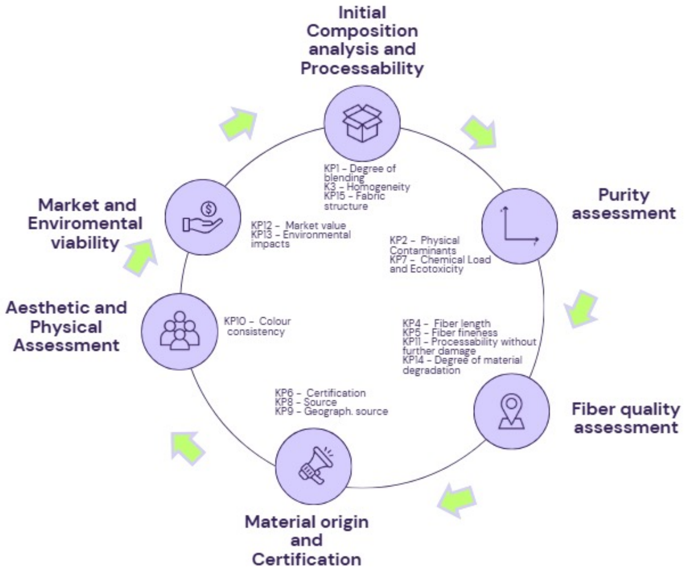


Figure 9: Proposed logical sequencing of Key Parameters (KPs) in the TIOR methodology

5.2.1.1 Assessing Economic value early in the decision process: the Textile Economic Recyclability Index – TERI - as a potential entry index

Whilst all parameters included in the methodology are considered essential, at now, for assessing recyclability, it is becoming increasingly clear that some may require prioritisation within the decision-making sequence, as anticipated above in "optimization of resources". In particular, the economic viability of recycling a given textile material could serve as a logical first step within a decision tree framework, always considering the various recycling methodologies which involve different costs.

In this regard, the Textile Economic Recyclability Index – also referred to as TERI – may be considered a potential primary parameter in the overall assessment process.

TERI offers rapid method for determining whether it is economically worthwhile to recycle a specific textile waste stream.

It does so by comparing either the market value of the recycled output with the price of the corresponding virgin raw material (TERI 1), or the total cost of recycling with that same benchmark (TERI 2).

In future developments of the methodology, TERI could be positioned as the first decision node in a broader tree-based logic: should the TERI score fall below a certain economic threshold, the material might be redirected towards lower-grade applications or excluded from further processing; conversely, materials with high economic potential would proceed to further technical and application-specific evaluation.

Objectives of TERI

- Supporting companies in making decisions based on concrete economic data.
- To make the most of each textile waste based on operating costs and the final market.
- Stimulate supply chain efficiency, avoiding unnecessary phases and optimizing economic margins.
- Improve the possibility of making investments in new technologies
- Promote transparency and replicability by creating a comparable standard.

The TERI formula in two variants:

TERI 1, measures the market competitiveness of recycled materials compared to virgin raw materials.

$$\textbf{TERI 1} = \frac{\textbf{Recycled Output Price}}{\textbf{Price of Virgin Raw Material}}$$

Or

$$\textbf{TERI 2} = \frac{\textbf{Total Recycling Cost}}{\textbf{Price of Virgin Raw Material}}$$

TERI 2, evaluates the economic efficiency of recycling processes relative to the cost of virgin input.

Example of Reduced Calculator Excel Sheet

TERI 1
= Recycled Output Price / Virgin Raw Material Price

Material	Price of Virgin Raw Material (€/kg)	Recycled Output Price (€/kg)	TERI %	Assessment
Cotton	1,39 €	1,60 €	115%	Not Convenient
Polyester	0,95 €	1,30 €	137%	Not Convenient
Wool	11,27 €	3,00 €	27%	Convenient

TERI 2
= Total Recycling Cost / Virgin Raw Material Price

Material	Price of Virgin Raw Material (€/kg)	Total Recycling Cost (€/kg)	TERI %	Assessment
Cotton	1,39 €	1,50 €	108%	Not Convenient
Polyester	0,95 €	1,20 €	126%	Not Convenient
Wool	11,27 €	2,50 €	22%	Convenient

Advantages of TERI

- Flexibility: suitable for heterogeneous and dynamic flows.
- Economics: focuses on real marginality, not just theoretical sustainability.
- Pragmatism: allows for quick evaluations on a lot basis.
- Decision support: Reduce uncertainty in choosing technologies and partners.
- Supply chain optimization: avoids unprofitable processes and suggests more sustainable alternatives.

Future Prospects

TERI can become a European standardisation tool, useful for:

- Define minimum criteria for the economic viability of textile recycling.
- Reward high **TERI** supply chains through incentives.
- Integrate the index into digital systems (e.g. corporate dashboards, logistics platforms).
- Accurately identify the economic weaknesses in recycling methods to more effectively target financing and subsidies.
- Calculate more easily the feasibility of new technologies to be applied.

We recommend future development of a more nuanced version, **TERI+**, integrating yield, logistics, incentives, and end-use alignment into a more accurate economic model.

It is important to recognise that the TERI index reflects current market conditions. As such, it serves as an effective tool for short-term, fast-track decision-making: when a material is clearly not economically viable today, the index helps avoid unprofitable recycling processes. However, this should not become a reason to systematically discard materials that score low under present circumstances.

On the contrary, **low TERI scores should trigger strategic action**. If certain textile waste streams – such as polyester – are currently uneconomical to recycle, this highlights the need for targeted research and development efforts. Reducing processing costs, developing new technologies, or enhancing specific technical attributes of secondary raw materials could make these materials more competitive than virgin alternatives in the future.

Without such forward-looking investment, the risk is that materials considered “not viable today” will continue to be landfilled or incinerated indefinitely. The TERI index, therefore, is not only a tool for assessing value: it can also serve as a **strategic indicator** of where innovation and policy support are most urgently needed to unlock circularity. In few word, a material deemed uneconomical today (low TERI) may become viable in the future through process innovation, improved sorting, or product redesign. Therefore, materials with low TERI values should not be discarded outright but flagged for R&D investment and innovation support, particularly within ReHub infrastructures.

Clarifying TERI vs. Market Value - TIOR Parameter KP13

Within the TIoR, one of the key parameters (KP13) is **Market Value**. This reflects the perceived desirability and demand for a recycled material within the relevant market.

On the other hand, **TERI** is a separate pre-assessment tool, in the idea of the decision tree step, that evaluates whether recycling the material is economically viable when comparing output value and recycling costs with the cost of virgin materials.

For example, a wool-based textile waste may have a high “Market Value” score within TIoR (e.g. 100/100) because recycled wool is in strong demand. However, the same material could receive a *low TERI* score if the costs of sorting, processing, and recycling are still higher than the economic return — indicating a current economic barrier to recycling despite market potential.

Thus, while Market Value contributes to the technical-applicative scoring of TIoR, TERI functions as a preliminary economic checkpoint. Their coexistence enables a more complete understanding of both market attractiveness and economic feasibility.

5.2.2 Concluding remarks on the TIOR methodology

The current section presents the foundation for a methodology to evaluate the recyclability of textile materials waste - a starting point for what could become a robust and standardized framework.

However, to achieve a fully developed and operational methodology, several key steps remain unaddressed:

- **Data Collection for different families of textile recycled materials**: gathering quantitative data from industry stakeholders is essential. This will enable the calibration of scoring ranges and provide a realistic picture of current material flows. It would be import to register a new close cooperation between recyclers, manufacturers and end-users for better align material preparation with market needs and application requirements.
- **Laboratory Testing**: parameters like pollutant levels (e.g., APEOs, flame retardants) and physical properties require validation through rigorous testing ("standard tests") to ensure accuracy and reliability. It would important to define, for each key parameter the methodology and the standard to refer for the measurement.
- **Application-Specific Insights**: more detailed studies are needed to understand how different recycled materials perform in specific applications.
- **Standardization**: Developing clear and universally accepted standards for evaluating recyclability across various applications, and so different sectors, is necessary to promote consistency and industry-wide adoption of textile waste.
- **Advanced testing infrastructure**: investments in tools and technologies are required to measure application-specific properties with precision and scalability.

Incorporating this index into the material selection and evaluation process for recycled textiles also presents significant challenges. The parameters outlined in this methodology must be measured accurately, yet several open questions remain:

- **How should the parameters be measured?**
- **Who is responsible for these measurements?**
- **Can automation play a role in some measurements?**
- **What are the costs associated with this evaluation process?**

These challenges highlight the complexities of implementing such an index in practice. Nevertheless, integrating this methodology into the recycling value chain offers a promising opportunity to make material selection more informed, sustainable, and aligned with circular economy goals. Addressing the gaps and questions outlined here will be critical to transforming this initial framework into a practical, standardized, and widely accepted tool for the textile industry.

5.2.3 Refining the Scoring system and weight system through the Data collection

The current scoring ranges for each parameter (e.g., long fibers = 90 -100, short fibers = 40) are primarily based on theoretical assumptions, literature reviews, and qualitative inputs. However, without a significant base of quantitative, real-world data, these scores may not fully reflect the complexities of industrial processes or material behavior in the textile recycling system.

An important phase of data collection across different families of recycled textile materials is suggested because it could:

- Validate existing Scoring: by systematically testing materials, we can observe how parameters like fiber length, contaminants, or blending actually impact recyclability. This validation ensures the scoring aligns with real-world outcomes.
- Calibrate Scoring ranges: for example, a current range of 40–100 might be adjusted if evidence shows that short fibers rarely achieve more than 50% recyclability in specific applications. This refinement would make the scoring more precise and relevant.
- Identify hidden patterns: large-scale data could reveal insights about materials that don't align with the initial scoring logic, leading to the identification of new trends or exceptions.

The same approach could be suggested also for adjusting parameter weights. Data collection would allow for a more quantitative weighting system by observing the actual impact of each parameter on recyclability and application suitability. Certain parameters may carry different levels of importance depending on the end use: for instance, durability might have a high weight for technical textiles but a lower one for insulation materials. Quantitative data would help fine-tune these application-specific weights.

By integrating extensive data from testing and industry feedback, the recyclability index could evolve into a far more robust tool.

Practical Steps in Data Collection

To achieve these outcomes, data collection should focus on:

1. **Testing across material Families:** Quantitative analysis of fiber types, blending, contaminants, and physical properties, measuring the list of Key parameters defined (KP1, KP2, KP3 …, KP x) across different textile waste families (FAM1, FAM2, FAM3 …, FAMx)

	KP1	KP2	KP3	xxxx	KPx
FAM1					
FAM2					
FAM3					
….					
FAMx					

2. **Application-Based Testing:** Collecting data on how recycled materials perform in different use cases such as apparel, technical textiles, or non-wovens. This process involves assigning specific weights to the key parameters on their relevance to each application, and, as specified before, with the involvement of the specific experts of each potential sector. By considering the unique requirements of each application, the methodology ensures that the weighted parameters (FAM1, FAM2, FAM3 …, FAMx) accurately reflect the material's suitability and performance for that specific use case.

Example 1 – Apparel and Fashion

	KPw1	KPw2	KPw3	xxxx	KPwx	Total (∑KPw normalized to 0-100)
FAM1						
FAM2						
FAM3						
….						
FAMx						

Example 2 – Non-wovens

	KPw1	KPw2	KPw3	xxxx	Total (∑KPw normalized to 0-100)
FAM1					
FAM2					
FAM3					
….					
FAMx					

These scores for each application, derived from normalized and weighted parameters, will provide a clear comparison of how well each material family aligns with the requirements of a particular use case.

For each specific application, the weighted scores will generate a ranking of material families, highlighting:

1. The most recyclable and suitable material families for the given application.
2. Material families that are less recyclable or less appropriate for that application.

For example:

- *Application: Non-Woven Fabrics*
  - *FAM1: Total Score 85 (highly suitable).*
  - *FAM5: Total Score 70 (moderately suitable).*
  - *FAMx-1: Total Score 50 (less suitable).*

2. **Calculation of the Overall Index of recyclability:**

The final step in the methodology involves calculating the Overall Index of Recyclability for each material family. This index consolidates all weighted parameter scores across applications into a single, comprehensive metric that reflects the material's overall recyclability potential.

The **Overall Index of Recyclability** provides a holistic score that integrates:

- The performance of the material across multiple parameters.
- Its suitability for diverse applications.

For example:

- **Recycled Polyester:** Overall Index = 88 (high recyclability).
- **Cotton-Polyester Blend:** Overall Index = 72 (moderate recyclability).
- **Recycled Cotton:** Overall Index = 55 (low recyclability).

The ultimate outcome of the methodology integrated with the data collection and fine-tuning of the scoring and weighted systems, would be a **multi-dimensional, data-driven tool** that provides actionable insights for stakeholders

It's important to underline that the database system would serve as the backbone for making informed decisions about material selection and usage.

The final system would not be static, it would function as a **feedback loop**: new data and technological advancements could continuously refine the scoring ranges, weights, and recyclability classifications.

Performance results from real-world applications could validate or adjust the index, ensuring it remains relevant as Industry practices evolve.

5.3 Looking Ahead: from Waste-Centric evaluation to Traceability-based design

The methodology presented in this chapter is designed to assess the recyclability of textile waste materials at their end-of-life, regardless of their origin, composition history or prior tracking. This reflects the current state of the textile system, where the vast majority of waste flows, especially post-consumer textiles, lack structured traceability and often arrive in recycling facilities as heterogeneous, undocumented materials.

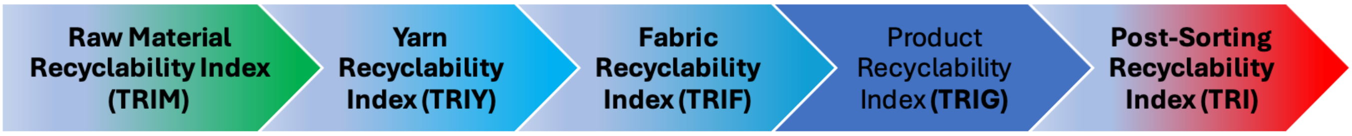
The Index TIOR developed here responds directly to this reality. It offers a pragmatic, criteria-based framework to evaluate the circular potential of existing textile waste, based solely on the observable and measurable characteristics of the material itself. This makes it immediately applicable to current challenges: large volumes of textiles that must be sorted, repurposed, or recycled, despite having no digital passport, no upstream certification, and no design-for-recycling considerations at the time of their production.

However, the future of circular textiles points toward a system where traceability becomes embedded from the earliest stages of a product's lifecycle. As EPR schemes, digital product passports and sustainability regulations become standard, new forms of recyclability assessment will emerge. In that context, it will be possible - and necessary- to develop indices that evaluate materials not just at end-of-life, but at design and sourcing stage, anticipating their circular performance before they enter the market.

This evolution will enable a shift from reactive to proactive circularity. *The recyclability of a material will no longer be reconstructed at the waste stage, but designed and documented upstream, allowing for real-time decision-making and optimized system flows*. A traceability-based index will then become the natural evolution to the current TIOR, expanding its utility from the waste stream to the full product lifecycle.

In this perspective, the current method should be seen as a foundational tool for today's needs, and a stepping stone toward a more integrated and predictive recyclability strategy for tomorrow's circular economy.

5.3.1 Proposal for multi-layered Textile Recyclability Index: for regular textile production looking forward the end of life



To improve decision-making in textile recycling, enhance traceability, and maximize material recovery, the report presents a structured and progressive recyclability model composed of five interconnected indices: TRIM (Raw Material), TRIY (Yarn), TRIF (Fabric), TRIG (Garment), and TRI (Post-Sorting).

Together, these levels reflect a holistic approach to recyclability assessment across the textile value chain.

The TRI – Textile Recyclability Index in particular is proposed as a scoring system that begins at the design stage of textile products and follows the material through its transformation into garments and eventually into post-consumer waste. TRI is not a static score calculated at end-of-life, but an incremental index that accumulates value based on design and production decisions made upstream. This approach sets TRI apart from TIOR: while TIoR assesses recyclability post-sorting, based on material families and physical properties, TRI would allow the product to arrive at the hub already embedded with its recyclability data, derived from its documented history across design, production, and distribution phases.
For each decision that facilitates recyclability, circularity or waste reduction (e.g., using mono-materials, enabling disassembly, avoiding hazardous treatments, choosing certified inputs), points are added to the TRI score. This accumulation continues through:

1. Raw Material Recyclability Index (TRIM)
Scope: Evaluates the recyclability of fibers and blends before they are spun into yarns. TRIM consider all the key factors that determine the characteristics and value of the blend.

2. Yarn Recyclability Index (TRIY)
Scope: Measures the ability of yarns (simple or twisted) to be recycled effectively. TRIY consider all the key factors that determine the characteristics and value of the single and twisted yarn calculated also considering the previous index.

3. Fabric Recyclability Index (TRIF)
Scope: Assesses the recyclability of woven, knitted and non-woven textiles. TRIF consider all the key factors that determine the characteristics and value of the fabric calculated also considering the previous index.

4. Garment Recyclability Index (TRIG)
Scope: Evaluates garments and textile products based on their design for recycling. TRIG consider all the key factors that determine the characteristics and value of the garment calculated also considering the previous index for all the component used to build the garment.

5. Post-Sorting Recyclability Index (TRI)
Scope: Determines how textile waste can be processed after collection and sorting. The key factors to be considered are TRIG, condition of collected textiles (wearable, damaged, contaminated), classification into mechanical vs. chemical recycling streams, etc.

OVERVIEW: The Five Recyclability Indices (with dependencies)

Level	Code	Depends on
Raw Material	TRIM	—
Yarn	TRIY	TRIM
Fabric	TRIF	TRIY
Garment	TRIG	TRIF + design
Post-Sorting	TRI	TRIG + condition + value

How the Indices Connect

From Raw Material to Product Design:

- A high **TRIM** (fiber-level) leads to a high **TRIY** (yarn recyclability) and supports better recyclability for fabrics (**TRIF**) and final products (**TRIG**).
- Complex blends and treatments lower the recyclability scores at each step.

From Product to Post-Sorting:

- A garment (**TRIG**) with a high recyclability score ensures better classification in waste sorting (**TRI**), improving recovery rates.
- Products with mixed materials, coatings, or inseparable components score lower and often end up in downcycling or waste streams.

Decision Support & Applications:

- Textile Manufacturers: Use **TRIM/TRIY/TRIF** to design more recyclable products. Use this information for Eco-design policy.
- Fashion Brands: Implement TRIG to improve circular design strategies.
- Recyclers: Apply TRI to optimize sorting and recycling efficiency, having more information and traceability.
- Regulators & Policymakers: Establish incentives or restrictions based on recyclability scores.

Advantages of the Textile Recyclability Index System

- The proposed multi-layered Recyclability Index (TRI) offers a structured framework that brings clarity, traceability, and actionable insights to the textile value chain, from raw material selection to post-consumer waste sorting. It needs for shared digital infrastructure (e.g., Digital Product Passports)

TRI draws its score directly from the conditions established by eco-design decisions made during the phases of product development. In this regard, it is important to mention another complementary deliverable developed within the RegioGreenTex project: the report entitled *"Linee guida di eco-design"*. This third report offers **practical guidance for making informed and traceable design choices** in line with circularity principles, across the various life cycle stages of textile products. Based on these structured recommendations, the TRI could **build its scoring system directly upon the criteria and priorities already outlined**, enabling a coherent and operational link between product design/production/distribution/use strategies and end-of-life recyclability performance.

Until these enabling conditions are in place, TRI remains a strategic framework under development — yet its architecture is conceptually mature and designed to close the gap between design-for-recycling and effective circularity at scale.

For this reason, TRI is presented in this report as a **visionary tool**, to be co-developed with brands and designers once enabling conditions exist.

In a future digital ecosystem where eco-design is mandatory and every product has a traceable profile, TRI could become a key performance indicator guiding sustainable product development.

6. Unlocking demand: Applications of recycled textile materials as the key to a Circular Textile Economy

6.1 Introduction: No Market, No Recycling

In the context of Europe's green transition and the growing pressure on the textile sector to meet circular economy goals, one fact has become clear: textile recycling will not thrive unless stable and diversified markets for recycled materials are created, and scientific, economic, and engineering studies must determine the advantages of recycled materials.

This point has been emphasized repeatedly by recyclers, sorters, and sector stakeholders interviewed as part of this research: without applications of recycled textile materials, there can be no recycling. The existence of recycling capacity alone is insufficient. Even well-designed hubs for textile waste collection and sorting, such as the emerging ReHubs, risk becoming inert storage facilities without market-driven reintegration pathways if the sorted textile fractions they produce have no viable outlet.

It is not enough to collect and sort textile waste. To close the loop, recycled materials must be reintegrated into production cycles across various sectors. These materials must meet performance standards, be cost-effective, and respond to real market needs. Only then can investments in recycling technology, sorting automation, and hub infrastructure be justified and made sustainable.

Stakeholders in the textile value chain - including municipalities, recyclers, technology providers, and fashion brands - are united in one belief: market pull is critical. If there are no buyers for recycled materials, regardless of how advanced the sorting or recycling process may be, then the system collapses under its own weight.

This insight is especially relevant now, as the EU Waste Framework Directive and the Textile Strategy for Sustainable and Circular Products impose ambitious targets, such as mandatory separate collection of textiles by 2025, EPR and product traceability. These policies will increase textile waste volumes, especially from fast fashion and synthetic blends, many of which are difficult to recycle back into yarn.

Without clear and attractive end markets, investments in sorting and recycling facilities risk becoming stranded assets. As a result, innovation in applications - not just technologies - is now a strategic priority.

6.2 The Central Role of Applications

The circular economy is not about waste management: it is about resource recovery and reintegration.

Therefore, the challenge is to transform textile waste into valuable inputs across sectors such as:

- Construction
- Automotive
- Furniture and Interior Design
- Packaging
- Agriculture and Horticulture
- Apparel, Fashion Accessories and Footwear

- Electronics and Appliances
- Geotextiles
- Gadgets and Industrial Products
- Floriculture
- Cleaning and hygiene
- Infrastructure
- Household devices

Each of these sectors has different regulatory frameworks, technical standards (e.g., fire safety, acoustic performance, and hygiene), and consumer expectations. Therefore, **adapting recycled textile outputs to each sector's needs is a key task,** as is working with designers and manufacturers to co-develop solutions that integrate these materials effectively. In this regard, the TIOR methodology (Ref. Chapter 5) wants to provide an additional layer of support, as it seeks to integrate and weigh all recyclability criteria in relation to specific end-use applications, ensuring that material flows are matched to the most suitable and value-preserving pathways.

Innovation must therefore occur not just in recycling processes but also in designing applications, building cross-sector collaborations, and developing new business models.

6.2.1 From Sorting to Solutions: exploring cross-sector applications


Next Technology Tecnotessile, in collaboration with a network of industrial and research partners, has carried out within several projects, different efforts to explore realistic and sector-specific applications for textile materials that cannot be reintegrated through fiber-to-fiber recycling – which today represent the largest share of textile waste.

Unlike traditional circular models focused on re-spinning waste into new yarns, AIMAG targets the **"orphan fraction" of textile waste**:

- Multimaterial blends
- Short fibers
- Contaminated or colored offcuts
- End-of-life garments that are unfit for reuse or re-spinning

These materials, unsuitable for mechanical carding or re-fabrication, would normally be discarded, incinerated or relegated to extremely low-value uses. Specific researches explores how they can be converted through mechanical transformation into composite materials, felts, padding and technical layers, feeding into a variety of industrial sectors.

The analysis resulted in a wide-portfolio of applications across different sectors, mapped by potential market size, technical feasibility and regulatory complexity. Examples include:

Sector	Examples of Products
Construction	Thermal/acoustic insulation, underlays, felts
Furniture/Interiors	Rigid panels, padding, decorative elements
Automotive	Seat padding, door panels, insulation layers
Footwear	Insoles, sandals
Apparel & Accessories	Bags, backpacks, recycled garments
Geotextiles	Infrastructure membranes, soil stabilization
Packaging	Reusable boxes, insulating fillers
Home Appliances	Noise-dampening mats, thermal barriers
Gadgets & Objects	Hangers, displays, small items
Floriculture	Compostable pots, textile mulching covers

This cross-sectoral approach confirms what experts already anticipated: **there is no single "silver bullet" application**. Instead, the strength of recycled textiles lies in their **adaptability across sectors**, provided that innovation is sustained and regulatory gaps are addressed.

The analysis goes far deeper than product-matching. It identifies a set of **systemic bottlenecks** that prevent recycled textiles from scaling into value-preserving applications.

Key Obstacles Identified in the AIMAG Study

1. **High Regulatory Barriers**
   Sectors like construction, automotive, public interiors and marine require compliance with strict standards. Many recycled materials cannot yet demonstrate consistent compliance, particularly when blends or variable-source fibers are involved.

2. **Fragmented Certification Landscape**
   The same material must often be certified multiple times depending on the sector. Existing standards rarely accommodate materials with recycled, non-homogeneous origins. Even where performance is high (e.g. fire-retardant felts), the lack of harmonized eco-labeling schemes blocks market entry. However, in certain sectors – such as apparel and home textiles – certifications like GRS or OEKO-TEX have already facilitated market access for recycled materials, proving that harmonized and trusted schemes can accelerate adoption when aligned with industry needs.

3. **Downcycling Dominance**
   Most textile-to-product pathways lead to low-cost, low-margin uses, such as painter's cloths, basic stuffing, or general packaging fill.

4. **Lack of awareness and trust among designers and buyers, especially in design-oriented sectors**
   Especially in architecture and high-end interior sectors, professionals are still reluctant to specify recycled textile composites - due to unfamiliarity, image concerns, or fears of inconsistency. This cultural barrier can be more impactful than cost or technical fit.

5. **Unrealized Potential of Post-consumer Waste**
   The studies also highlights that post-consumer waste, such as offcuts and unsold stock, is easier to certify and has higher performance potential (color uniformity, known fiber content). Yet this stream is often underutilized due to lack of infrastructure for traceability and collection.

6.3 Co-Designing the Future: Concepts from students of "Università degli Studi di Firenze"

As part of the broader strategy to stimulate innovation in the reuse and recycling of textile waste, the seminar "**TEXTILE RE_BIRTH**" represented a significant educational and experimental initiative. Organized by the University of Florence and commissioned by Next Technology Tecnotessile as part of the R&D activities of the EU project RegioGreenTex, the seminar took place between November 2024 and January 2025, engaging students from the Bachelor's Degree in Textile and Fashion Design and the Master's in Fashion System Design.

Led by professors and researchers from DIDA and DICUS departments, the seminar aimed to develop ideas that enhance the value of textile waste within a circular economy framework. The program was designed in response to the pressing demands of the European Directive mandating the separate collection of textile waste, in force from January 1, 2025. The current recycling infrastructure is still insufficient, and new approaches are urgently needed to turn waste into opportunity.

Fancy yarn spinning waste

By-product from dye test trials

Selvedge waste

Notably, several of the companies interviewed for this report were also actively involved in the seminar, offering valuable support to students by providing technical insights. They also provided a wide variety of textile waste thus allowing students to work with real, industry-grade discarded resources.

Their generous participation strengthened the link between research, education and industry.The seminar's main objective was to **generate forward-thinking concepts to extend the life cycle of textile materials and prevent their incineration or landfill disposal**. It did so through three primary strategies:

- Experimenting with new product ideas and industrial applications for textile waste;
- Inspiring companies and designers with innovative reuse concepts;
- Collaborating with textile companies from the Prato district that provided characterized scrap materials for use in the design process.

The methodology combined methodologies such as “Design Thinking”, a human-centered innovation approach that integrates desirability, technical feasibility, and business viability and “Material Tinkering”, a hands-on, empirical method that promotes learning through direct interaction with discarded materials.

Students worked in groups and followed a two-phase process:

1. **Material analysis and benchmarking** of best practices, including company visits and desk research;
2. **Prototyping and technical documentation**, where each group selected a final sector (e.g., packaging, interiors, automotive) and created a tangible prototype and technical sheet detailing raw materials (in particular secondary raw material), product specs, production process, maintenance, and end-of-life.

The initiative successfully met its goals, not by delivering market-ready solutions, but by **fostering a creative exploration of textile waste as a resource**. It also served as a powerful learning tool, bridging academia, industry, and sustainability, and cultivating a new generation of designers trained to approach textile waste not as a problem, but as a design opportunity.

The prototypes generated were in total 10. What follows is a selection of the most relevant and promising results in terms of potential impact on the textile recycling and reuse market.

The application concepts developed during the TEXTILE RE_BIRTH seminar offer a vivid snapshot of how design-driven thinking can unlock new narratives for textile waste. Despite being prototypes, these projects demonstrate an impressive breadth of sectors - from interior design and packaging to fashion accessories, pet products, and educational tools - showing that recycled textiles are not confined to low-value, utilitarian uses. On the contrary, many of the proposals embrace expressive aesthetics, multifunctionality, and customization, signaling a clear potential to challenge the perception of recycled materials as inferior or unattractive.

Technically, the projects reveal a keen sensitivity to the constraints of recycled materials - such as fiber heterogeneity and mechanical limitations - and respond through thoughtful material pairing, modularity, and low-tech manufacturing. Many embrace no-additive processes (e.g., mechanical interlocking, felting, pressing), enhancing both ecological and economic feasibility. Others explore hybrid approaches that integrate recycled textiles with biodegradable binders or bioplastics (e.g., PLA), pointing toward future-ready composite solutions.

Crucially, the students’ outputs push the boundaries of conventional circularity by proposing not only sustainable materials but also emotionally engaging objects - such as customizable jackets, playful slippers, and educational kits - that invite user attachment and care. This emotional durability is often overlooked in industrial recycling scenarios, yet it is key to truly extending product lifecycles.

Collectively, these applications act as a creative manifesto: they demonstrate that textile waste can be a medium for innovation, storytelling, and value creation. They also highlight the untapped design potential in categories often ignored by mainstream recycling efforts—like pet care, fashion display tools, and compact urban gardening. If supported by industrial partnerships and certification pathways, many of these ideas could evolve into viable market propositions. As such, they represent not only student exercises but also seeds of transformation in how society conceives, values, and utilizes textile waste.

Sector: Interior Design
Project Name: **WOOLLOCK**

Project Overwi Overview:

WOOLLOCK proposes an alternative method for valorising yarn twisting waste. The recycling process is entirely mechanical, requiring no chemical additives, resins, or water. The production technique involves manually interlocking short fiber scraps using steel knitting needles of varying diameters, depending on the desired yarn thickness.
Inspired by the *dreadlocks* technique, this approach creates durable, tactile, and aesthetically distinctive cords from textile offcuts—without relying on external binders. The result is a low-impact, craft-based solution that combines sustainability with expressive material language, particularly suitable for interior applications.

Key Features:

- 100% mechanical process
- No water, glue, or chemical use
- Adaptable yarn thickness
- Suitable for soft interior elements or decorative accessories

Designers: **Angela Di Sciorio**, **Giorgia Volpini**

Sector: Pet Accessories
Project Name: **P-BAG – The Must-Have Travel Accessory**

Project Overview:

P-BAG is a multifunctional pet carrier made entirely from recycled materials, designed to comfortably and safely transport pets in various situations. The product features a 3-in-1 functionality: it works as a handbag, a car travel crate, and a portable pet bed.
The design is the result of careful material selection and process research aimed at creating a product that is lightweight, impact-resistant, non-toxic, easy to clean, safe, comfortable, and durable. The materials used include:

- Recycled nylon (outer shell)
- Reused car seatbelt (polyester)
- Needle-punched panel made from thermopressed textile scraps
- Sub-carded padding (a mix of animal, plant, and synthetic fibers)
- Cotton thread and zipper

Key Features:

- Three configurations in one product
- Smart use of diverse textile waste streams
- Durable and washable construction
- Designed for everyday use and mobility

Designers: **Alessia Bertolini**, **Kevin Matracchi**

Sector: Apparel (Outerwear and Technical Clothing)
Project Name: **TRANSLUCID**

Project Overview:

TRANSLUCID is a bold and unconventional outerwear concept that blends innovation and sustainability through expressive design. The project presents a transparent, waterproof jacket made from recycled ripstop nylon, filled with reclaimed textile padding (a wool/synthetic blend), offering both warmth and comfort.
The jacket's transparency not only showcases its recycled interior but also allows aesthetic personalization by varying the color and texture of the inner filling, making each piece unique and emotionally engaging.

Key Features:

- Transparent, water-resistant outer shell (recycled nylon ripstop)
- Recycled mixed-fiber filling for insulation
- Customizable inner look through padding variation
- Functional, expressive, and sustainability-oriented design

Designers: **Martina Paoletti, Azzurra Rizzuti**

Sector: Object Design / Visual Merchandising
Project Name: **ECOMEK**

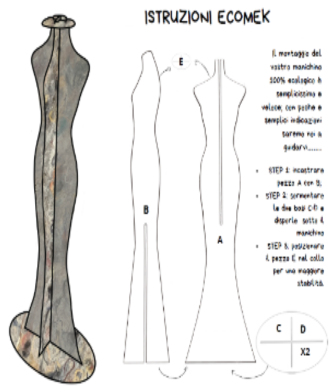
Project Overview:

ECOMEK addresses the growing need for innovative and sustainable solutions in the fashion industry. It is a lightweight, modular display mannequin made entirely from pressed nonwoven textile waste panels. Designed to be easily disassembled and transported, ECOMEK responds to contemporary demands for efficiency, versatility, and environmental responsibility—ideal for exhibitions, fashion shows, and trade fairs.
The sleek, minimal design not only optimizes storage and setup but also serves as a communication tool for brands committed to sustainability. The project also explores laser-cutting techniques and a zero-waste design methodology, adding technical precision to its low-impact approach.

Key Features:

- 100% made from recycled textile waste
- Modular, flat-pack design for easy transport
- Suitable for retail displays and events
- Incorporates laser cutting and zero-waste design principles

Designers: **Laura Marisa Rinaldi, Maria Vittoria Misesti**



Sector: Interior Design & Construction
Project Name: **Bio-Tex**

Project Overview:

Bio-Tex explores the reuse of one of the least exploited forms of textile waste: dust and fine fibers. Often overlooked, this residual material gains new value in Bio-Tex through a focus on its aesthetic and tactile potential.
The project investigates experimental combinations of textile dust with alternative binders such as plaster paste, alginate, and rabbit glue, resulting in a series of unique prototypes that differ in mechanical properties, texture, and composition. These material blends offer promising applications in 3D printing and the production of decorative wall tiles.

Key Features:

- Valorization of textile dust—a typically discarded by-product
- Experimental blends with natural binders
- Variability in texture and structural properties
- Potential use in additive manufacturing and architectural finishes

Designers: **Alfredo Lazzarini**

Prototype 1

Textile waste (sub-carded), dust, and rabbit glue

Prototype 5

Textile waste (sub-carded), dust and plaster

Prototype 8

Textile waste (sub-carded), dust and alginate

6.4 Applications are the linchpin of Circularity

If Europe is to succeed in building a circular textile economy, the development of real, scalable applications for recycled textile materials must move to the center of policy, investment, and design agendas. Without viable end uses, even the most advanced recycling and sorting technologies will be rendered ineffective. **Demand - not just supply - drives the system.**

Recent research and pilot initiatives carried out by Next Technology Tecnotessile together with industrial and research partners demonstrate that it is possible to move beyond low-value downcycling and instead target high-potential sectors with composite materials, felts, and technical products derived from non-recyclable textile fractions. However, the study also highlights systemic barriers that must be addressed such as regulatory fragmentation, certification gaps, cultural resistance and lack of infrastructure for post-consumer waste valorization.

At the same time, the **TEXTILE RE_BIRTH seminar** shows that innovation does not rest solely with industry. Educational design experimentation, when connected to real waste streams and supported by companies, can produce imaginative and technically sound ideas that challenge the perception of recycled textiles as marginal materials. These speculative but grounded proposals, ranging from modular insulation to multifunctional pet carriers, point toward **new market niches**, product languages, and emotional strategies that could redefine value in textile reuse.

To truly unlock the potential of textile recycling, Europe must invest not only in technology but also in:

- Policy support and simplification of certifications;
- Cross-sector collaboration between recyclers, designers, and manufacturers;
- Design education that embraces circularity and material intelligence;
- Public-private R&D programs focused on end-use development;
- Strong communication around environmental and social impacts.

7. Conclusions of the Research and Path Forward

This report addresses the broader challenge of the **circular textile economy**, which encompasses a wide spectrum of strategies – from reuse, repair, refurbish to chemical recycling and the development of new bio-based materials. Within this wide landscape, however, the present study deliberately focused on a specific subsystem: **mechanical recycling**, the historical core of the Prato and Biella districts. This choice reflects both the long-standing expertise available and the wealth of empirical knowledge that can be extracted from these contexts. By analyzing this well-established practice, the report provides a realistic lens to identify patterns, challenges, and opportunities that can also inspire the development of other circular solutions across Europe.

One of the clearest findings is that mechanical recycling, while highly refined and efficient for certain materials, is no longer sufficient on its own. A growing portion of today's textile waste - especially blended, low-quality materials - cannot be treated mechanically. This calls for the integration of chemical and hybrid recycling technologies, not to replace existing expertise, but to complement and expand it in response to new material challenges.

At the same time, stakeholders consistently emphasized that technology alone is not enough. Recycling is economically and environmentally viable only when there are concrete downstream applications. From fashion to construction, from automotive to agriculture, recycled textiles must find diversified, high-value uses. Without this pull effect, even the most advanced collection and sorting infrastructures risk becoming stranded assets.

The study also revealed persistent bottlenecks along the value chain:

- Sorting still relies heavily on manual labor and tacit knowledge, with automated solutions limited in scope and scale.
- Most textile waste flows lack reliable data on composition, treatments, or provenance, creating a traceability gap that complicates both operational choices and compliance with EU regulations such as REACH.
- Skills are at risk: many competences that sustain textile recycling today are passed on informally and risk disappearing with generational turnover. There is no structured training pipeline for new professional profiles such as circular designers, textile recycling technicians, or quality assessors of secondary raw materials.
- Certification systems, while crucial for transparency and trust, remain fragmented and costly, especially for SMEs. A more harmonized and performance-based framework is urgently needed.

In response to these challenges, this report introduced the first version of a Textile Recyclability Index (TIOR). Designed not as a one-size-fits-all rating but as a decision-making tool, TIOR links material properties with feasible applications, offering practical guidance for recyclers, designers and institutions on how to direct material flows where they are most valuable. Two complementary indices - on economic recyclability (TERI) and on recyclability-by-design (TRI) - are also under development, further broadening this methodology.

Looking forward, the research highlights that the future of textile circularity in Italy rests on moving from siloed practices to integrated ecosystems. Textile waste must be seen not as a residual burden but as a distributed, untapped resource that requires coordination, innovation, and systemic support.

7.1 Toward a two-level architecture for Recycling Hubs

A critical part of this vision is the development of Recycling Hubs (ReHubs). In the framework of the RegioGreenTex project, this concept is articulated as a two-level architecture:

Local Recycling Hubs – these represent the physical infrastructures currently under development, with advanced sorting and recycling capacity. They will ensure large-scale collection, selection, dismantling, and processing of textile waste.

Italy Greentex Hub (IGH) – this is the non-physical, service-oriented platform designed to support and empower the local hubs. Conceived as the national coordination layer, the IGH provides transversal functions that directly respond to the gaps identified in this study.

The ReHubs are envisioned as enabler of textile circularity, entrusted with the task of connecting infrastructures, companies and knowledge into a coherent system. To fulfil this role, the Hub will deliver a portfolio of macro-services. In the following a first proposal of this new portfolio defined through extensive consultation with stakeholders and grounded in evidence-based analysis, that together represent the cornerstone of Italy's leadership in the European circular transition.

Infrastructure	Automated and manual sorting lines	**Testing & Certification**	Material testing lab
	Pre-treatment and dismantling stations		Ecotoxicological screening
	Baling		Certification advisory services for textile waste-based products
	Smart storage	**Mapping & Assessment**	Classification systems for textile waste families
	Logistics		Recyclability assessment (TIOR)
	Traceability and data infrastructure		Technology readiness mapping
Mapping & Assessment	Value chain mapping for textile waste transformation and valorisation		Carbon Footprint and/or ESG Assessment
		R&D&I support	Study and testing of 5Rs solutions, with open access for innovators, SMEs, or startups
			R&D for the development of new high-value applications based on different textile waste flows/Families
			R&D&I Project Development and Network Building with National/EU ReHubs and Centres of Excellence on Textile Waste
		Application Development and Market Activation	Application scouting and managing of co-design workshops
			Design and prototyping of products for innovative applications based on different types of textile waste families
			Showroom of 5R materials and solutions
			Go-to-market support for innovative textile waste-based applications
		Skill Development & training	Training and brainstorming sessions with brands
			Training academy for awareness raising, skills development and new professional profiles for processes, services, new business models, and digital tools to support the consolidation of a new ecosystem for textile waste valorisation.
			Knowledge transfer

Table 18: Proposal of Hard and Soft/enabling services to be delivered by a ReHub for the Textile Waste Valorisation

The IGH, as the “soft” coordination and innovation platform complementing the “hard” infrastructures of Prato and Biella, represents a pivotal step in aligning Italy with Europe’s circular textile ambitions. By combining tradition, industrial capacity, and systemic innovation, this architecture ensures that textile waste is not only processed but also transformed into new opportunities for industry and society.

The tools exist. The urgency is clear.

The next step is collective action, linking infrastructures, services, markets and people into a unified framework for circular textiles.

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This report contains images generated with the support of Artificial Intelligence.

9. ANNEX 1

Framework of Questionnaire used in the Interviews

INQUADRAMENTO Azienda e Inquadramento di dettaglio sulla prevalenza sottoprodotto/rifiuto tessile		
1	**Ragione sociale** dell'Azienda	Aperta
1b	La vostra è un'azienda di committenza o di sub-fornitura?	Aperta
2	Il vostro ciclo di lavorazione tratta sottoprodotti, ricicla rifiuti tessili o entrambi?	Chiusa
Questionario per le Aziende che utilizzano sottoprodotti/rifiuti tessili per le loro produzioni e/o per i loro prodotti		
3	Quali sono i **fornitori** dai quali vi procurate i sottoprodotti* tessili?	Aperta
3a	E dove si trovano **geograficamente**?	A scelta: - Italia - Nord Europa - Medio Oriente - Asia - Africa
3b	Notate delle differenze tra le forniture di diversi fornitori?	Facoltativa - Aperta
3c	Ci sono dei criteri di selezione tra i vari fornitori alternativi?	Aperta
4	Quante tonnellate di sottoprodotto tessile* acquistate all'anno?	Aperta
4a	Siete in grado di fornirci le **quantità per singola composizione**? Di queste composizioni qual'è il tipo di substrato? (filato, tessuto, ...)	Aperta
4b	Con quale grado di accuratezza conoscete la composizione all'acquisto del materiale tessile?	Aperta
5	Con il sottoprodotto* che acquistate, ricevete anche una **scheda tecnica** con le specifiche dello stesso?	Chiusa (SI, NO)
5a	I dati da scheda tecnica vengono riportati fino a conclusione del processo di rilavorazione per mantenere la tracciabilità del materiale?	Aperta
6	Quali sono i **criteri di acquisto**?	Aperta
6a	Come valutate il **potenziale di riciclabilità** dei singoli materiali che comprate per ciascuna famiglia di prodotto (in base alla composizione e al fornitore)?	Aperta
6b	Quali sono le restrizioni o **barriere all'accettazione del sottoprodotto*** presso la vostra azienda? (Ad esempio il rispetto di alcune certificazioni)	Aperta
7	Quali **informazioni ulteriori** vorreste ricevere sul materiale in entrata?	Aperta
7a	Dovete effettuare **analisi/test di laboratorio** per la verifica di alcuni parametri necessari per normative e/o per effettuare determinate lavorazioni?	Chiusa (SI, NO)
7b	Se sì, quali **parametri** verificate e con quali test?	Aperta
8	Con quali lavorazioni rivalorizzate i sottoprodotti*? E in quali percentuali usate i sottoprodotti rispetto al materiale vergine?	Aperta
9	Qual'è la **resa del materiale** in entrata?	Aperta
9a	I sottoprodotti che generate durante le fasi interne di lavorazione, vengono ulteriormente reimmessi in nuovi cicli di produzione?	Chiusa (SI, NO)
9b	Se Si, per quali impieghi e in quali quantità?	Aperta
GAP - Possibili difficoltà e problematiche riscontrate nelle fasi di produzione e gestione aziendale		
10	Quali sono le principali **difficoltà tecniche** che riscontrate nelle vostre lavorazioni di sottoprodotti* tessili?	Aperta
11	Come vi assicurate che i sottoprodotti* che rivalorizzate non possiedono **sostanze contaminanti o potenzialmente dannose**?	Aperta
12	Quali sono gli aspetti più critici dei **capitolati dei vostri clienti**? Quali di questi aspetti guidano/vincolano le scelte di acquisto dei sottoprodotti?	Aperta
13	In quale ambito riscontrate le principali difficoltà nel lancio/consolidamento del vostro business? (Ambito NORMATIVO - di SISTEMA - di MERCATO)	Aperta
14	Esiste un **sistema** o quali sono le attuali necessità di miglioramento **di raccolta/smistamento/condivisione** di sottoprodotti tessili tra aziende?	Aperta
15	Quali potrebbero essere **nuove applicazioni** da generare a partire dai sottoprodotti tessili?	Aperta
Aziende che GENERANO sottoprodotti/rifiuti Tessili - Questionario per le aziende che durante il loro ciclo produttivo generano sottoprodotti/rifiuti tessili		
3	Quale tipo di sottoprodotto* producete? Con quale substrato e con quale composizione?	Aperta
3a	Quali delle vostre lavorazioni impattano maggiormente sulla **generazione di sottoprodotti* tessili**?	Aperta
3b	Qual'è la quantità in tonnellate di sottoprodotti* tessili prodotti all'anno?	Aperta

INQUADRAMENTO Stakeholder		
1	**Ragione sociale**/nome dell'ente	Aperta
1a	Forma giuridica/Tipologia della società	Aperta
2	Quali sono le **tipologie di aziende** che vi commissionano il ritiro dei sottoprodotti?	Aperta (in base al prodotto in output)
2a	Dove si collocano **geograficamente** in modo prevalente?	Aperta
3	Come viene richiesto il servizio di **ritiro**?	Aperta
3a	Come gestite/elaborate gli **ordini di ritiro**?	Aperta
4	Chiedete una **pre-selezione dei sottoprodotti tessili**?	Aperta
4a	Su quali **criteri**?	Aperta
6	**Quanto materiale tessile (sottoprodotti)** ritirato all'anno in tonnellate?	Aperta
6a	Siete in grado di fornirci le **quantità** per singola composizione? Di queste composizioni qual è il tipo di substrato? (filato, tessuto, ...)	Aperta
7	Quali **dati sul sottoprodotto tessile** chiedete al produttore?	Aperta
7a	Riuscite a riportare tali **dati lungo tutto il processo** di gestione della futura materia prima-seconda ai fini della tracciabilità?	Aperta
7b	In quale modo?	Aperta
8	Come gestite i sottoprodotti **dopo la raccolta**? Viene per esempio effettuata un'ulteriore selezione?	Aperta
8a	Su quali criteri viene effettuata la selezione?	Aperta
9	Esistono dei criteri (standardizzati o interni) per determinare la **riciclabilità del sottoprodotto**?	Aperta
10	Avete una **mappatura dei sottoprodotti** in base a provenienza, fornitore o qualsiasi altro criterio, associata a un valore di riciclabilità della fonte? Esiste una suddivisione della riciclabilità in base alle diverse categorie (composizione/substrato)	Aperta
11	Quale è la **percentuale di reimpiego effettivo** sui sottoprodottii tessili raccolti?	Aperta
12	Avete **partenariati o accordi** con altre aziende o enti per il riutilizzo dei sottoprodotti tessili?	Aperta
13	Quali sono le **sfide principali** che incontrate nella gestione dei sottoprodotti per la generazione di materia prima-seconda? (Barriere alla raccolta – barriere durante la lavorazione)	Aperta
14	Avete già identificato opportunità per **migliorare l'efficienza o l'efficacia** della vostra gestione dei sottoprodotti tessili?	Aperta
15	In che modo le **certificazioni** ostacolano o favoriscono la raccolta e la rivalorizzazione?	Aperta
15a	In che modo la presenza di sostanze chimiche ostacola la raccolta e la rivalorizzazione?	Aperta
16	Quali sono i vostri **obiettivi a lungo termine** per quanto riguarda la gestione dei sottoprodotti tessili?	Aperta
16a	Come le nuove **normative europee** modificheranno lo scenario europeo della raccolta e rivalorizzazione del materiale tessile?	Aperta
17	C'è qualche altro aspetto importante riguardante la vostra attività di gestione dei sottoprodotti tessili che vorreste condividere?	Aperta

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