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TEXTILE RECYCLING SUPPLY CHAIN ANALYSIS BETWEEN UŞAK AND PAIMIO CITIES

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SCOPE OF THE REPORT

The scope of this report is to comparatively analyze the textile recycling supply chains of Uşak and Paimio cities, to develop improvement recommendations on the management of industrial and household textile waste, and to increase the sustainable textile production and recycling capacities of both cities.

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1. INTRODUCTION

This report has been prepared within the scope of the comparative textile recycling supply chain analysis between the cities of Uşak and Paimio, which is one of the main activities of the Collaborating for Sustainable Future: Accelerating Green Transition of Textile Sector Through Partnerships project supported by the EU Town Twinning between Turkey and EU - II (Twinning for a Green Future) Grant Scheme (TTGS-II) program.

The title of the project indicates that the fundamental aim of the project is to underpin a sustainable future through collaboration. Accordingly, the studies have been carried out towards this goal with the participation ofUsak Municipality alongside representative(s) from Paimio Municipality, Corporate Responsibility Association of Turkey (CR Turkey), Aegean Industrialists and Businesspeople Association (ESIAD), ZAFER Development Agency and other relevant stakeholders.The aim of this report is to comparatively analyze the textile supply chains of Uşak and Paimio cities, to develop improvement recommendations on the management of industrial and household textile waste, and to increase the sustainable textile production and recycling capacities of both cities. In addition, it includes analyzing the current status of textile recycling supply chains in Uşak and Paimio cities, making comparative analyses and proposing improvement strategies.

The rationale of this project relies on advancing both textile ecosystem in Turkey and Finland. In order to discover and get a grasp of the current situation of both clusters is vital to understand the room for improvement in both Usak and Paimio textile sectors. From an initial point of view, both cities have their advantages and deficiencies in their textile clusters. Usak city could be indicated as an outstanding example of industrialized textile production and recycling city that hosts various small and medium sized enterprises and advanced manufacturing factories. Uşak is an important city for recycling in Turkey. There are two organized industrial zones that are mainly concentrated on leather and textile sector. In the recycling facilities located here, textile wastes and plastic bottles are recycled and brought back into the economy. In the above-mentioned facilities, 620,000 tons of textile waste is brought to the economy annually, and a serious contribution is made to the overall Turkish economy thanks to the yarns obtained from recycling. Today, 80 percent of the recycled fibers produced in the existing recycling facilities in Turkey are produced in Uşak. With the products obtained as a result of the processing of textile wastes, an annual export of 75 million dollars is made to 62 countries. In the same vein, in addition to textile waste, 35 percent of plastic bottle waste in Turkey is processed in Uşak. It is possible to mention an annual figure of 187 thousand tons in plastic bottles. Uşak Municipality, which strives to become a center recycling especially in textile sector and carries out many activities to protect the city as well as the natural structure of the city with its environmentally sensitive activities, has started to work on new projects.

On the other hand, Finland offers a lot of good practices when it comes to sustainable textile production and recycling. In particular, Paimio city hosts a textile network called Telaketju that is powered by cutting-edge technologies with full of innovative features. It is a cooperation network that forwards textile recycling. The aim is to develop the collection, sorting out and refining processes of end-of-life textiles. Moreover, the network enables the development of business models related to discussed circular economy. In Telaketju, a national ecosystem of knowledge is being advanced, building a platform for the creation of new and strong industry with multidisciplinary collaboration. The Finnish industry has recognized that its international opportunities are in sustainable, slow, and ethical fashion sub-segments. However, there are gaps in the local upcycling value chains.

Hence, both textile cluster has to offer to the other and this potential should be unveiled. Through conducting a comparative supply chain analysis Usak city will draw lessons from Paimio's innovative approach to the textile production and facilities. Also, this document will reveal the room for further improvement for both textile ecosystems, which in results pave the way for productive field visits and meetings during subsequent project activities.

2. SUPPLY CHAIN AND SUPPLY CHAIN MANAGEMENT

The increasing growth of the global market and the increase in the number and complexity of products have caused the only connection between the supplier and the consumer to be based on a long network. Businesses needed new approaches to increase their profitability and efficiency and to get rid of the intense competitive pressure.Due to the acceleration of globalization and the increasing expectations of customers, the concept of supply chain has come to the fore in the industry to shorten product development time, increase quality, reduce costs and improve process efficiency.[1]The concept of supply chain, which emerged as a result of these needs, has been defined in many ways to date.

The supply chain is the collaborative network of companies that provide products and services to the market.[2]

A supply chain is a network of interconnected organizations that work together and cooperate to control and manage the flow of materials and information from suppliers to users.[3]

The supply chain is a network formed by many businesses, where raw materials are procured, converted into semi-finished products, and the final product is distributed to customers through distribution channels.[4]

The supply chain is the network of facilities and distribution options that perform the processes of procuring materials, transforming these materials into semi-finished and finished products, and delivering these products to the customer.[5]

The supply chain is more than just the physical movement of goods from one place to another; it is also the circulation of information, money, and the creation and development of mental capital.[6]

The supply chain can be defined as the distribution of enhanced customer and economic values through the harmonious management of all products and related information from sourcing to consumption.[7]

As can be seen from many different definitions, if the concept of supply chain is to be explained in general; It covers activities such as management of supply and demand, supply of raw materials, production and assembly, storage, inventory management, order management and distribution of products to customers, etc. and also includes the information systems necessary to sustain all these activities.

In this study, a supply chain approach was used to address the processes of textile recycling sectors from raw materials to final products for the cities of Uşak and Paimio.

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[1]Filiz, A. Ç. (2023). Analysis of Sustainable Supply Chain Management Criteria and Supplier Selection Problem in the Textile Industry with the Analytical Hierarchy Process Method. Journal Of Busıness Research, 15(1), 640-658.
[2] Carter, C. R., &Ellram, L. M. (1998). Reverse logistics: A review of the literature and framework for future investigation. Journal of business logistics, 19(1).
[3] Tan, K. C., Kannan, V. R., Handfield, R. B., & Ghosh, S. (1999). Supply chain management: an empirical study of its impact on performance. International journal of operations & production Management, 19(10), 1034-1052.
[4] Lee, H. L., & Billington, C. (1992). Managing supply chain inventory: pitfalls and opportunities. Sloan management review, 33(3), 65-73.
[5] Ganeshan, R., & Harrison, T. P. An Introduction to Supply Chain Management May 24, 2007.
[6] Ayers, J. B. (Ed.). (2001). Making supply chain management work: Design, implementation, partnerships, technology, and profits. CRC Press.
[7] Jayaraman, V. (2006). Production planning for closed-loop supply chains with product recovery and reuse: an analytical approach. International Journal of Production Research, 44(5), 981-998.

Supply chain analysis is an analysis method used to systematically identify, define and evaluate the operations that an organization implements in a certain order for the services or products it offers, together with the strengths and weaknesses in the chain, within the framework of a business philosophy that considers this order as a value chain and accepts that the company adds meaning to these operations thanks to the value chain.Porter defines the value chain as the most basic tool for systematically examining all operations carried out by a sector in the integration process, which he sees as the key factor in gaining competitive advantage.[8]In other words, supply chain analysis is a method of separating operations in the sector into strategically important operations and understanding the effects of these operations on cost and value.[9]Supply chain analysis is essentially a systematic method for examining the development of competitive advantage. In this respect, the model is used as a useful analysis tool in defining the main competence areas in a sector and determining the operations that are effective in gaining competitive advantage. Competitive advantage arises from many different operations that a company performs, such as design, production, marketing, delivery and product support services. In order to better understand the operations that provide competitive advantage, it is necessary to start from the value chain in its general scope and then to determine the appropriate operations specific to that sector.[10]From the perspective of managers, supply chain analysis is considered a powerful tool used to identify the main operations that make up the value chain within the company and to have the potential for sustainable competitive advantage of the company. The competitive advantage of an organization stems from its ability to perform important operations in the value chain better than its competitors. It is seen in many industries that companies do not perform all operations on their own, from product design to spare part production, from final assembly to delivery to the end user. Organizations usually appear as a part of the value system or supply chain. However, the value chain analysis should also include the entire value system in which the organization's operations are located. The value chain may also include collaborations that do not result in mergers of companies but envisage long-term partnerships. However, such coalitions should include the coordination or sharing of the value chain by the collaboration partners.[11]

The goal of the supply chain framework is to maximize value delivery while minimizing costs. The supply chain describes all operations (such as production, purchasing, distribution, and consumption) required to deliver a product or service from its conceptual design to its delivery to the end consumer.[12]A supply chain is a system that includes components such as material suppliers, manufacturing facilities, distribution services, and customers that are connected by the forward flow of materials and the backward flow of information.In their efforts to manage their supply chains, organizations should focus on the supply chain structures they are members of that are most critical to their own success. These supply chains have the greatest potential to create a competitive advantage for the organization and thus contribute to the organization's continued success. When examining supply chains, it is first necessary to distinguish between internal and external supply chains.[13]

Supply chain management is an integrated management approach that enables the planning and control of all movements throughout the distribution channel from suppliers to the end user.[14]Supply Chain Management can be defined as the process of reducing costs by optimizing the route a product takes from the producer to the consumer in the form of raw materials. If we expand this definition in its simplest form, Supply Chain Management is a set of activities that

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[8] Porter, M. E. (2008). Competitive advantage: Creating and sustaining superior performance. Simon and Schuster.
[9] Stabell, C. B., & Fjeldstad, Ø. D. (1998). Configuring value for competitive advantage: on chains, shops, and networks. Strategic management journal, 19(5), 413-437.
[10] Porter, M. E., & Advantage, C. (1985). Creating and sustaining superior performance. Competitive advantage, 167, 167-206.
[11] Porter, M. E. (1982). Competitive strategy. RAE-Revista de Administração de Empresas, 22(2), 44-46.
[12] Kaplinsky, R. (2004). Spreading the gains from globalization: what can be learned from value-chain analysis? Problems of economic transition, 47(2), 74-115.
[13] Handfield, R. B., & Nichols, E. L. (2002). Supply chain redesign: Transforming supply chains into integrated value systems. Ft Press.
[14]Ellram, L. M., & Murfield, M. L. U. (2019). Supply chain management in industrial marketing–Relationships matter. Industrial Marketing Management, 79, 36-45.

aim to reduce inventory costs by ensuring the most appropriate flow of the product, to minimize critical decision-making processes by reducing uncertainties in product shipment, and to minimize planning expenses and order costs by standardizing the order system.Supply chain analysis is used to systematically uncover, identify and analyze strengths and weaknesses in supply chain management.The main idea in supply chain analysis is that as more value is provided to the customer, higher competitive power is gained. If the value created by a business exceeds the cost of performing value operations, this business can be considered profitable. In the sector, values emerge by performing a group operation. In addition to the value-delivering operations of the companies, activities are carried out within a value system consisting of vertical operations that include their suppliers upstream and channel members downstream. And in supply chain analysis, all activities in this system are examined.

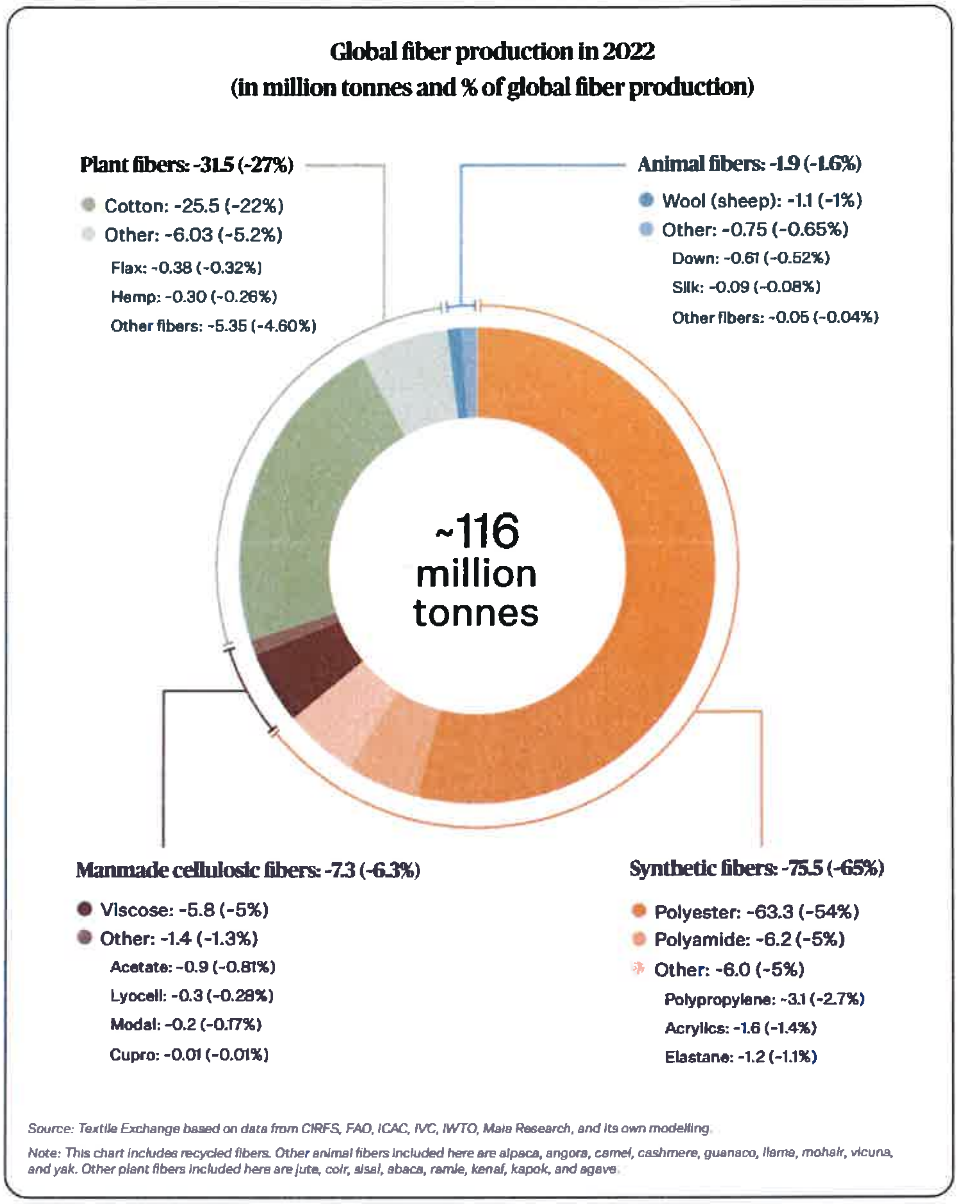
3. TEXTILE RECYCLING

The unconscious use of exhaustible resources in the world has brought about waste problems in production processes and caused global threats such as greenhouse gas formation, ozone layer depletion and climate change. According to the statistics of the World Economic Forum, environmental problems that have become visible and tangible as a result of industrialization and the resulting climate change have gained more importance since 2011. When recent years (2017 and later) are examined, climate change and environmental problems are the most important global risks.[15]

The latest report, which covers materials for the fashion, textile, and apparel industries as well as other sectors, reveals that global fiber production rose from approximately 112 million tons in 2021 to a record 116 million tons in 2022. If current trends continue, production is projected to reach 147 million tons by 2030.[16]Details of global fiber production are shown in the Figure 1.

[15] World Economic Forum, Global Risks Perception Survey 2023-2024.
[16] Materials Market Report 2023, Textile Exchange, December 2023.

Figure 1. Global fiber production in 2022

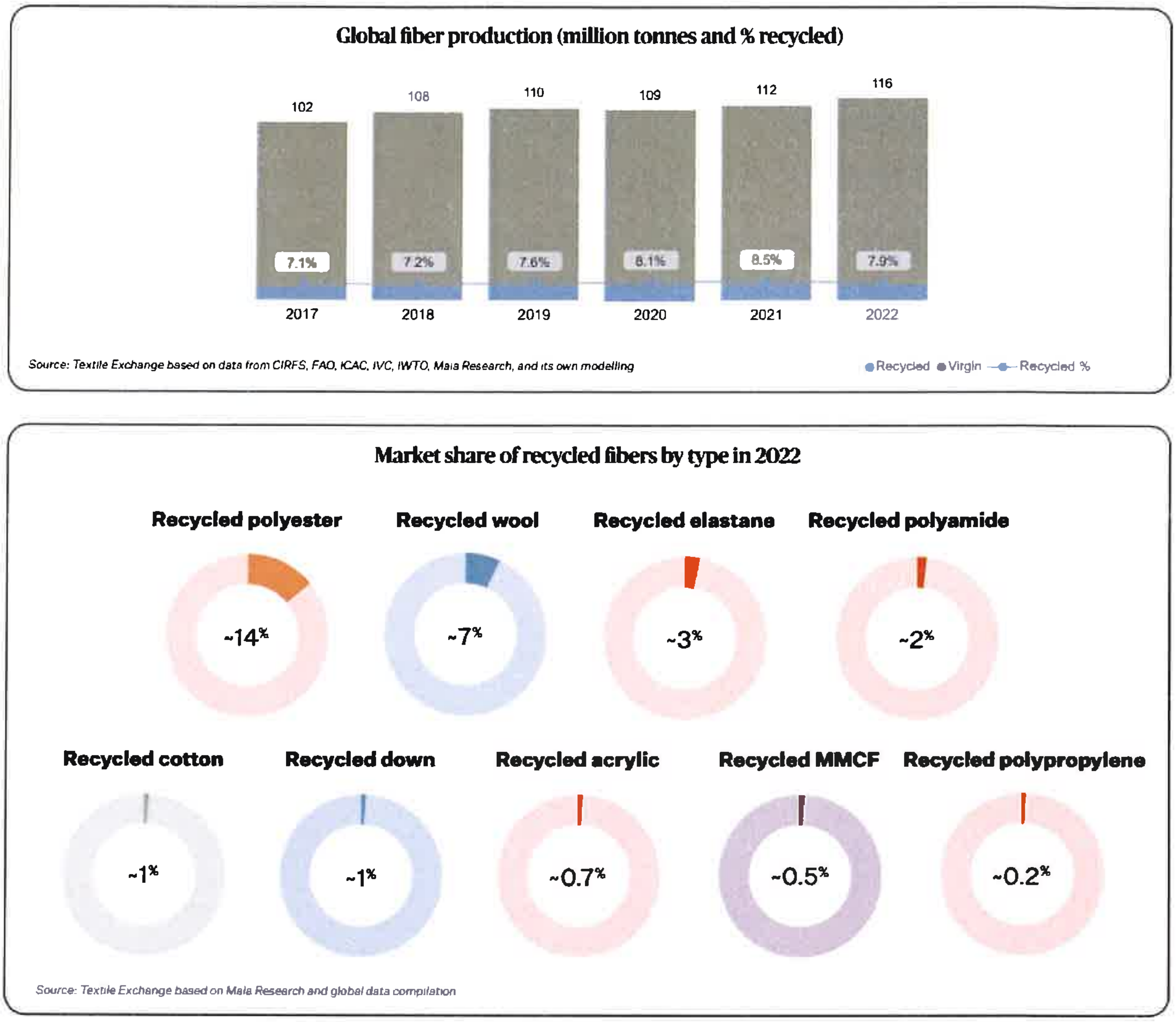


In 2022, the proportion of natural fibers produced through sustainability programs saw a modest increase, with cotton rising from 25% in 2021 to 27%, and wool from 3% to 4.3%. However, the production of virgin fossil-based synthetic fibers also grew, from 63 million tons to 67 million tons. Polyester remained the most widely produced fiber globally, accounting for 54% of production in 2022.

Despite years of growth, the overall share of recycled fibers dipped slightly from around 8.5% in 2021 to 7.9% in 2022. This decline was primarily due to a reduction in the market share of recycled polyester, which is largely derived from plastic bottles, falling from 15% in 2021 to 14% in 2022. Factors contributing to this decrease include increased competition for PET bottles and challenges in scaling textile-to-textile recycling. In 2022, less than 1% of the global fiber market was composed of pre- and post-consumer recycled textiles.[17] Recycling amounts and recycled fiber details against global fiber production are given in theFigure2.

[17] Materials Market Report 2023, Textile Exchange, December 2023.

Figure 2. Global fiber production and recycling details



In the EU-27 and Switzerland, approximately 7 to 7.5 million tons of gross textile waste are produced annually, which equates to just over 15 kilograms per person. By 2030, this annual total could increase to between 8.5 and 9 million tons, or just under 20 kilograms per person.[18]

These findings highlight the urgent need to accelerate the transition to fibers from preferred sources, intensify efforts to reduce the use of virgin fossil-based materials, and invest in strategies that decouple value creation from the extraction of new materials.New approaches have had to be created in order for people to continue their life cycle without any problems. For this reason, the idea of recycling has begun to be adopted with increasing desire in recent years.

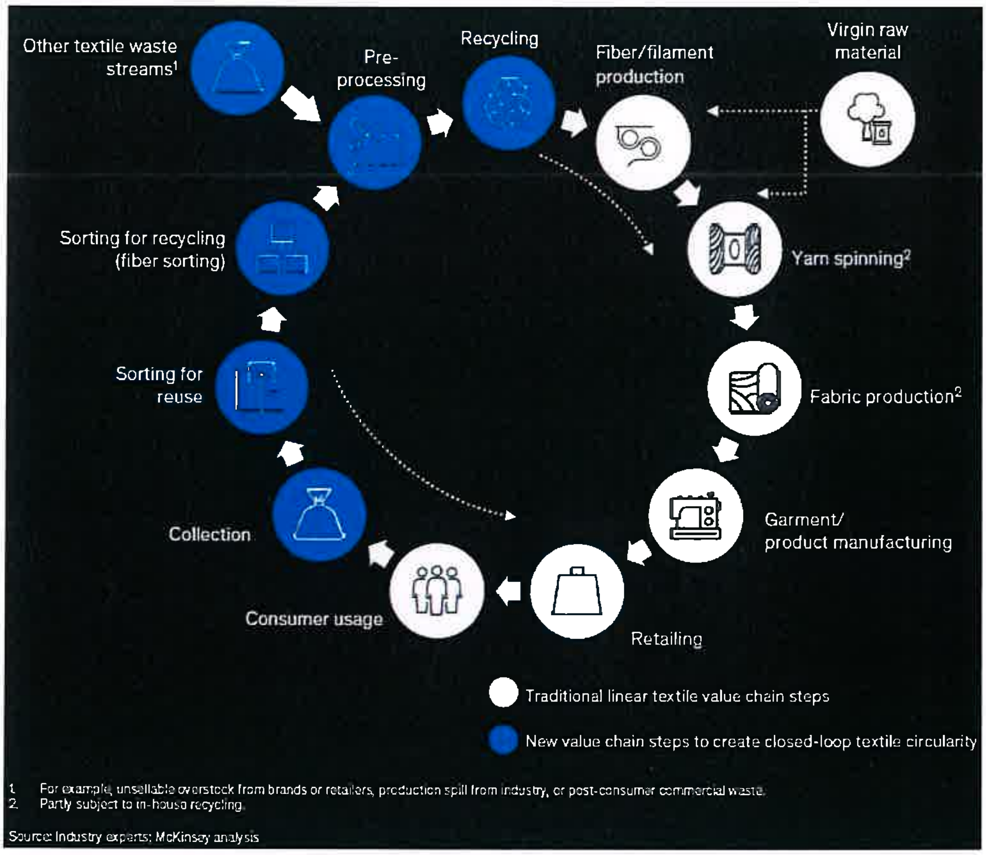
Recycling can be defined as the recycling of unused recyclable waste materials as raw materials for manufacturing processes using various methods.[19] These materials are textile, paper, glass, plastic, engine oil, battery, concrete, aluminum, organic waste, electronic materials and similar wastes.[20] Textile wastes are the wastes that occur in the production processes of textile production facilities or after consumption by consumers. Wastes from yarn factories are textile

[18]Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14..
[19] Veiga, M. M. (2013). Analysis of efficiency of waste reverse logistics for recycling. Waste Management & Research, 31(10_suppl), 26-34.
[20] Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14.

manufacturing wastes and textile wastes of consumers. In other words, these wastes can be classified as pre-consumption and post-consumption. Pre-consumer wastes consist of textile, fiber and cotton industry by-product materials that are re-manufactured for clothing, furniture, automotive, home, building, bedding, coarse yarn, household goods, paper, aviation and other industries. Post-consumer wastes are defined as household goods made of clothing or textile materials that the consumer does not need to use and decides to throw away.[21]

Scaling up textile recycling could be a powerful lever for impact, as it addresses both upstream production by substituting virgin materials with recycled ones and the end-of-life waste challenge (Figure 3).

Figure 3. The closed-loop textile recycling value chain has the potential to revolutionize the clothing and textile industry



Recent advancements have moved many textile-recycling technologies from pilot phases to readiness for commercial scaling. As these technologies continue to evolve, they are expected to offer cost-competitive alternatives to virgin fibers.However, the major challenge lies in the feedstock itself. All textile-recycling technologies depend on a steady supply of predictable textile waste for recycling. Currently, the feedstock supply is constrained by the complexities involved in collecting, sorting, and pre-processing textile waste. To fully realize the potential of closing the loop in clothing and textiles, further technological innovation and enhanced collaboration among industry stakeholders are crucial.

Textile recycling is a key solution for addressing the textile-waste issue, alongside efforts to minimize waste generation, extend garment lifespans, and promote the second-hand economy. The potential to reduce the carbon footprint by up to 90% for certain fiber types compared to virgin materials, coupled with decreased land and water use and lower chemical pollution,

[21] Domina, T., & Koch, K. (1997). The textile waste lifecycle. Clothing and Textiles Research Journal, 15(2), 96-102.

highlights the substantial environmental benefits of textile recycling.[22] In evaluating the recycling technology landscape, it's important to consider the different types of fibers, as recycling technologies are often specific to particular fibers or blends. Currently, polyester, cotton, manmade cellulosic fibers (MMCF), and polyamide are the predominant fibers in the clothing and home textiles sectors, together accounting for approximately 90% of the total volume.[23]

Fiber blends are also crucial, as many recycling technologies require a minimum level of fiber purity for effective closed-loop processing. Analysis from Norna's fiber-composition data suggests that 50 to 60% of polyester or cotton fibers may achieve 100% purity.[24] Pure fiber streams are generally more straightforward to recycle using closed-loop technologies. Besides fiber composition, other factors that affect a garment's or textile's recyclability include product characteristics (e.g., single vs. multi-layer fabrics), hard components (e.g., buttons and zippers), soft components (e.g., labels and threads), heavy coatings or finishes, prints, color (particularly for mechanical recycling), fabric construction (e.g., knitwear is easier to recycle mechanically than woven fabrics), and contamination such as mold or oil stains.

Textile waste recycling is generally done with the following methods:

A) Mechanical methods

B) Thermo-mechanical methods

C) Chemical methods

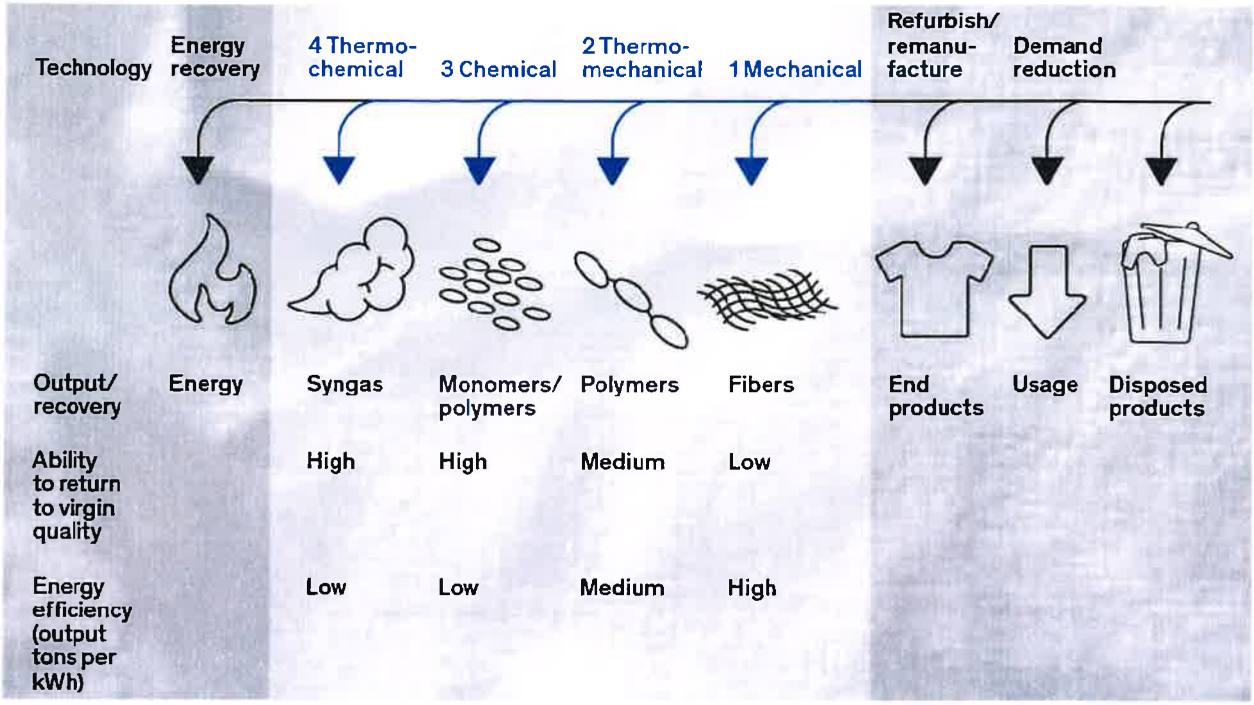
D) Energy generation

E) Other methods

Textile waste; in the mechanical method, it is turned into fiber form that can be used in textile (yarn, fabric and nonwoven surface) production, while in the thermo-mechanical method, it is melted again and turned into granule form, and the granules are used in plastic and fiber production. When looking at the chemical method, especially synthetic-based waste materials are generally recycled to raw material or intermediate product by using chemical depolymerization methods, and the products obtained from here are used in various areas such as textile finishing materials, fibers, unsaturated resins. Due to the high calorific value of textile waste, the use of waste as fuel has been discussed, but since oil reserves are decreasing day by day, burning synthetic-based materials should be the last option.[25] The most important point here is that synthetics are petroleum-based materials and since they are obtained from fossil fuels, they cause air pollution by releasing significant CO2 gas into the atmosphere.[26]. Recycled fibers, when compared to other fibers, cause less damage to the environment, consume less energy, use fewer resources and are processed with fewer chemicals if they are not going to be dyed (Figure 4).

[22] Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14.
[23] Expert interviews; Preferred fiber and materials market report 2021, Textile Exchange, 2021.
[24] Norna is an artificial intelligence company that analyzes product information based on data obtained online (McKinsey Analysis, 2023).
[25] Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling–A review. Journal of cleaner production, 184, 353-365..
[26] Telli, A., &Babaarslan, O. (2017). Usage of recycled cotton and polyester fibers for sustainable staple yarn technology. Textile and Apparel, 27(3), 224-233.

Figure 4. Textile recycling types with their effects.[27]



3.1. Mechanical Recycling

Mechanical recycling employs physical processes like cutting and grinding to transform textiles into usable fibers. This method is commercially proven, energy-efficient, and cost-effective. It operates under the principle of "what goes in, comes out," meaning that the fiber composition of the textile waste is preserved in the recycled fibers. Mechanical recycling can be applied in both "open-loop" (primarily downcycling) and "closed-loop" systems. Presently, open-loop applications, such as the production of cleaning rags, shoddy fibers, and padding, represent the most developed market segments, with diverse end uses across industries including automotive, furniture, wall and floor coverings, and apparel.

However, the market analysis indicates that this technology faces a challenge in the quality degradation of recycled fibers, with a reduction in fiber length by 30 to 40 percent, which somewhat limits its application in closed-loop systems. Nevertheless, combining recycled, shorter fibers with virgin fibers can result in higher quality products, many of which are already available in the market. Additionally, innovations are emerging to address these challenges, such as "soft" mechanical recycling technology, which reduces fiber length by only 10 to 15 percent, and other advancements to enhance the mechanical recycling process.[28]

Textile wastes in the form of fiber balls, yarn pieces and fabric scraps are widely recycled using the mechanical recycling method due to its simplicity and cheapness.[29] In a mechanical recycling process, textile wastes are first sorted according to their fiber composition and color characteristics. Sorting helps to obtain recycled fibers, especially in similar fiber types and colors. After the sorting process, the waste material is first separated into small pieces, and then these

[27] Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14.

[28] Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14.

[29] Gun, A. D., & Oner, E. (2019). Investigation of the quality properties of open-end spun recycled yarns made from blends of recycled fabric scrap wastes and virgin polyester fibre. The Journal of The Textile Institute.

pieces are passed through a series of comb-type cylinders covered with sharp wires and the process continues by separating them into fibers.[30]Textile wastes are first classified (sorted), then cut into small pieces and finally opened in comb-like opening machines covered with opening wires called rag pulling machineor garnet and turned into fibers. The obtained fibers are either turned into yarn and used in the production of woven and knitted fabrics or used directly as fibers in the production of nonwoven surface fabrics.

Textile wastes should first be well classified according to their raw material, color and recyclability. This classification is of great importance for blending. For this reason, first the fabric scraps are sorted and separated. In the first sorting process, also called rough sorting, the scraps are roughly separated as dark and light colors. Then, the scraps are sorted according to the color catalog according to the final product planned to be produced. In this second sorting process, the fabric scraps are individually selected and carefully sorted according to the desired fiber color.

In the sector, scraps are generally divided into three groups according to their raw material with subjective methods: cotton, cotton/polyester and elastane (lycra). The most valuable ones are cotton scraps. The sorting process, in which many employees classify one by one according to both the raw material type and color type, is a very laborious and attention-demanding process. It is expected that the automation of this process will be made more advanced in the future with electronic applications and robotic processes instead of the human eye. In this state, the scraps that come to the business in bales, mostly by human power, are visually inspected and sorted according to the color catalogue, and are grouped as cotton, cotton/polyester and elastane (Figure 5).

Figure 5. Sorting process

As the second step, the clippings come to the cutting machine [88].

There are basically three different cutting machines.

• Rotary knife cutting machine

[30]El-Nouby, G. M. and Kamel, M. M. (2007). Comparison Between Produced Yarn from recycle Waste and Virgin Fibres in Tenacity and Elongation, Journal of Applied Science Research, 3: 977–982.

• Guillotine cutting machine

• Cutting mill

Generally, the rotary knife cutting machine is the most used. Textile wastes are fed to the cutting machine and after being cut into small pieces (20-260 mm long), they are passed through a puller (shredder) and/or garnet machine, turned into fiber form and included in the process.[31] The clippings, which were previously separated according to their raw materials and colors, are cut in the cutting machines and brought to smaller sizes. These machines consist of 4 parts: 1-Input section 2-Metal Detector 3-Guillotine 4-Output section. The cutting machine is shown in Figure 6. The clippings brought to the metal detector by means of the conveyor belt located at the input part of the machine are checked with sensors here to determine whether there is metal inside. If there is metal, the machine stops and the bundle in the metal detector is removed and thrown away. The scraps coming out of the detector are brought to the guillotine again by means of a conveyor belt. The scraps are cut and brought to smaller sizes by means of a knife moving up and down in the guillotine section. The scraps sucked from the guillotine section, by a vacuum system are poured onto the conveyor belt and carried to the vacuum channel. The scraps sucked by the vacuum channel are sent to metal chambers. Generally, fabric pieces are cut in width and length as 38 mm for openings to be used for cotton spinning. Fabric scraps are cut in two or three directions depending on the type of cutting machine.

Figure 6. Cutting machine

In the third step, the clippings come to the waiting/mixing rooms. The clippings coming out of the cutting machine are sucked by a vacuum system and brought to the metal rooms. These rooms are called Box Rooms in the sector. An example image of this room is given in Figure 7. The clippings are kept here for 24 hours. During this waiting, chemical substances such as silicone softener and antistatic are given to the clippings. These rooms can take 10-20 tons of material. The clippings resting here gain a soft and voluminous structure and are made ready to be opened.

Figure 7. Waiting/Mixing rooms

[31] Oner, E., & Kaya, S. (2023). Investigation of the use of hemp fibers in recycling spinning. Acta Scientiarum-Technology, 45.

In the fourth step, textile waste (scraps) that are cut into small pieces are opened and turned into fibers. Mechanical recycling machines called rag puller and garnets that rotate at high speed and have wires on them are used for fiber opening.

The rag puller machine is a fiber opening machine that resembles a carding machine, with a series of cylinders and drums covered with sharp metallic wires to open the cut pieces. The cylinder surface with metallic wires on it comes into contact with the textile waste and opens these textile waste materials into fibers. This process can include many passages from one to six. The puller machine belonging to the Balkan company is shown in Figure 8.

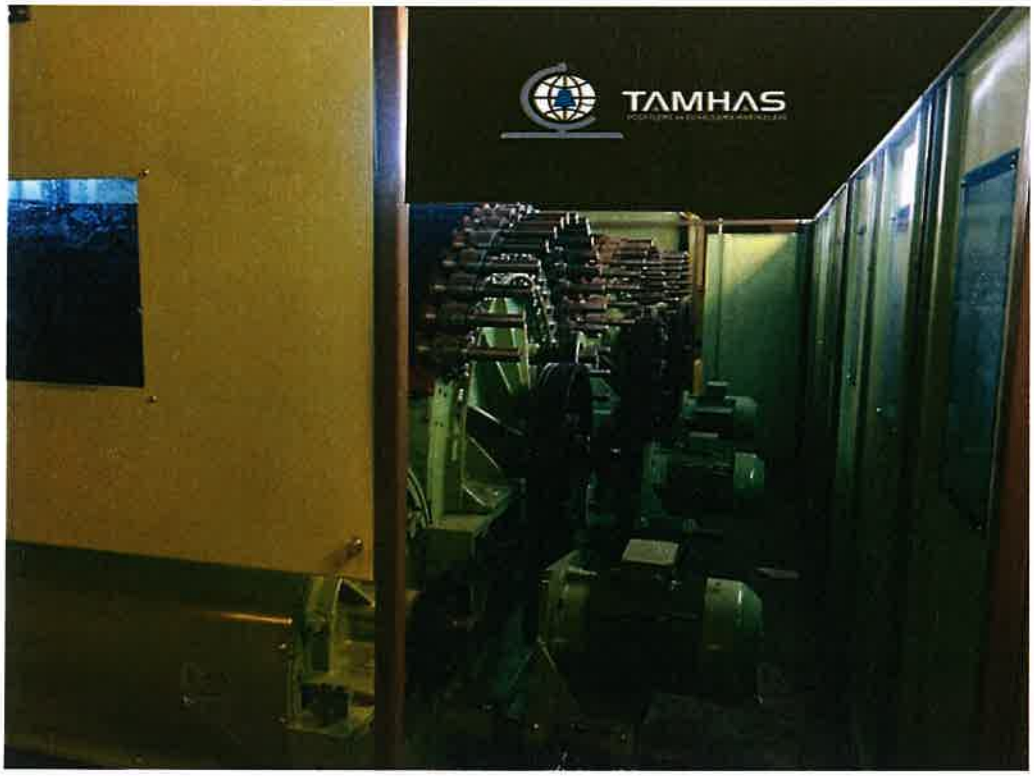
Figure 8. Rag puller machine

The basic quality parameter in this machine is that the clippings entering the machine are completely broken down and not knotted. There are two important settings in the machine at this point. The first of these is the adjustment called the regulation setting, which is the distance between the feeding cylinder and the spiked mat, and this adjustment is made manually by attaching a lever to the shaft on the side of the machine where the feeding cylinder is mounted to the machine and turning it. The second adjustment is the height adjustment between the two sorting shutters under the spiked cylinder and the spiked cylinder. This adjustment is made electronically. If the clearance is increased, the feedback will be higher, if the clearance is reduced, the clippings cannot be fully converted into fibers, neps are formed. There is no numerical value for these settings, and adjustments are made by finding appropriate values using the trial-and-error method. There is a vacuum channel at the exit of the machine. Thanks to this channel, the tired fibers are sucked and sent to the press machine, where they are pressed and turned into bales. This machine basically consists of 3 parts; 1- Input section 2-

Section where the cylinders are located 3- Output section. At the entrance of the machine, there is a section called the fireplace where the fiber enters the machine with a vacuum system. In the second section of the machine, there are feeding rollers and spiked rollers. There can be 6-7 pairs of rollers (one feeding roller and one spiked roller) in the opening machines. The feeding rollers are made of rubber and the small pieces that come to the spiked rollers through these rollers are converted into tired fiber in the spiked rollers. There is a section at the bottom of the machine where the parts that are not completely broken down are poured and sent back to the machine entrance. This feedback process is provided by an endless conveyor belt. In this process, the pieces are poured onto the conveyor by the effect of centrifugal force. When the pieces coming to the spiked roller hit the roller, a centrifugal force occurs on them in direct proportion to their size. With the effect of this force, the piece is thrown into the gap between the spiked roller and the sorting shutter and falls onto the conveyor belt located below.

Garnet machine is a fiber opening machine similar to a carding machine, covered with saw-tooth metallic wires, with drums and cylinders, used to open textile wastes with little or much twist. Garnet machines open textile solid wastes in a finer way. Garnet recycling & opening machine belonging to Tamhas company is given in Figure 9.

Figure 9. Garnet machine



In the garnet machine, fabrics obtained from long fibers such as wool and acrylic are opened, while in the sintering machine, fabrics obtained from short fibers such as cotton and viscose are opened. In some applications, the fiber particles coming out of the sintering are passed through the garnet machine once more and subjected to a second opening.In this machine, textile wastes are turned into fibers one by one, that is, they can enter the fiber blend. Two cylinders covered with sharp, curved metal needles transmit the waste placed on the machine's feed table to a drum rotating in a closed cage. The needles in the drum hold them, separate the entangled parts and throw them out of the cage with centrifugal force.

Finally, the recycled fibers are opened by the opening machines and turned into bales by pressing machines.

3.2. Thermo-mechanical Recycling

Thermo-mechanical recycling involves applying heat and pressure to melt synthetic textiles like polyester and polyamide, enabling the recovery of polymers. However, this technology is not suitable for natural fibers (such as cotton or wool) or man-made cellulosic fibers (like viscose). It is energy-efficient and has the potential to minimize quality degradation compared to traditional mechanical recycling methods. While thermo-mechanical recycling is well-established at a commercial level for non-textile waste (e.g., PET bottles) and has been demonstrated for textiles, there are still technical challenges to overcome, such as viscosity issues with PET. Additionally, the strict feedstock requirements—requiring more than 99% pure or compatible polymers—limit its current applicability in textile recycling.

Polyethylene terephthalate (PET) polymer, which is the most consumed polymer in the textile industry, can be converted into PET pellets (burr, flake) in recycling facilities from PET packaging, which is mostly used to market liquid foods such as water, soft drinks, oil, etc. PET pellets are obtained after a series of process steps such as breaking, washing, drying, etc. by sorting PET bottle waste from other waste.For optimum quality PET pellet production, separation of PET waste is an important and critical step.Thermomechanical recycling is the conversion of synthetic chips into fiber using the melt-extrusion method.In the mechanical method, fiber is obtained directly from synthetic pellets, while in the semi-mechanical method, the pellets are subjected to a fine-chopping process again and then converted into chips and fiber is drawn. While there is a material yield of 99% (1.01 kg flake - 1 kg fiber) in the mechanical method, the semi-mechanical method works with a yield of 94% (1.07 kg flake - 1 kg gypsum). In addition, energy savings of up to 60% are achieved in fiber production with material conversion.[32]Polyester fiber recovered with material conversion is expressed as r-PET. With the decrease in both energy costs and raw material costs, recycled fiber production has become a production method with an important economic advantage. In addition, r-PET fibers have less embodied energy and less carbon emission (carbon footprint), thus causing less damage to the environment.[33] The sample thermomechanical recycling machine line is given in Figure 10.

Figure 10. Sample thermomechanical recycling machine line

3.3. Chemical Recycling

[32]Shen, L., Worrell, E., & Patel, M. K. (2010). Open-loop recycling: A LCA case study of PET bottle-to-fibre recycling. Resources, conservation and recycling, 55(1), 34-52.

[33] Roca, E., &Herva, D. M. (2015). Ecological Footprints in the textile industry. In Handbook of life cycle assessment (LCA) of textiles and clothing (pp. 63-82). Woodhead Publishing.

Chemical recycling refers to a range of distinct technologies that utilize chemical processes to decompose fibers into their polymer or monomer components. Techniques that revert fibers to the polymer stage include pulping methods used to recycle cotton and man-made cellulosic fibers (MMCF) into a pulp comparable to dissolving wood pulp (DWP), which can subsequently be used to produce MMCF. Other processes, such as solvent-based or hydrothermal methods, allow for polyester and polycotton fibers to be recycled back into PET melt and cellulosic materials, which can then be respun into PET polyester fibers. The technologies that break down fibers to the monomer stage, including processes like methanolysis, glycolysis, hydrolysis, and enzymatic reactions, focus on recycling polyester and polyamide. These methods require further processing to transition from monomers (such as mono-ethylene glycol [MEG] and purified terephthalic acid [PTA]) back to polymers like PET, before the fibers can be regenerated. Although chemical recycling generally consumes more energy than mechanical recycling, its primary advantage is the production of fibers that are nearly equivalent to virgin quality. While full-scale commercial chemical recycling of textiles is not yet widely implemented, numerous companies are developing pilot projects and commercial plants, targeting both cellulosic materials (e.g., Lenzing, Renewcell, Södra, and Infinited Fiber) and synthetic materials (e.g., Eastman, Erema, Worn Again, Ambercycle, Gr3n, and Circ).[34]

Chemical recycling is to the process where polymers are broken down (as in polyester) or dissolved (such as cotton and viscose). This method can generate fibers that match the quality of those made from virgin materials. Sorted textile waste can be chemically processed to recover resources like protein-based fibers, which are used in wood panel adhesives, and cellulosic fibers, which can be utilized for bioethanol production.[35]Chemical recycling of textile waste presents a promising alternative, addressing some limitations associated with mechanical recycling. This process involves transforming polymeric waste by altering its chemical composition, thereby reverting it into monomers that can serve as raw materials for creating new polymers. Through chemical recycling, fibers can be broken down into monomers or building blocks and subsequently re-polymerized into new fibers that can be of equal or even higher quality. Nevertheless, there is a risk that hazardous substances from dyes, softeners, anti-wrinkle agents, and other common additives may persist or spread during the chemical recycling process. The presence of chemicals in textile waste can hinder recycling efforts, yet our understanding of their specific impacts and the extent to which they influence these processes remains limited.[36]

Color stripping is a widely used method to correct various shade discrepancies that arise during the dyeing or printing processes in the textile industry, serving as an effective decolorization technique. However, these methods have not been extensively implemented for recycling purposes. Technologies for removing color from textile waste include dye destruction and extraction.[37] Dye destruction techniques, such as oxidation and photodegradation, can damage polymers and affect the dyeability of the regenerated textiles. In contrast, dye extraction tends to cause less fiber damage, but it requires solvents with high dye solubility, and typically only partially removes the dye from the textiles. Successful stripping of reactive dyes has been achieved with 89–94% efficiency through a combined reductive treatment using sodium hydroxide and sodium hydrosulfite at elevated temperatures of 80°C to 100°C. Määttänen et al. reported that vat, reactive, and direct dyes could be effectively removed from textiles by employing a combination of various chemical treatments, including alkaline, acidic, hydrogen peroxide, ozone, and dithionite methods.[38] However, these processes may result in damage to

[34] Hedrich, S., Janmark, J., Langguth, N., Magnus, K. H., & Strand, M. (2022). Scaling textile recycling in Europe-turning waste into value. McKinsey's, 14.
[35] Juanga-Labayen, J. P., Labayen, I. V., & Yuan, Q. (2022). A review on textile recycling practices and challenges. Textiles, 2(1), 174-188.
[36] Baloyi, R. B., Gbadeyan, O. J., Sithole, B., & Chunilall, V. (2024). Recent advances in recycling technologies for waste textile fabrics: A review. Textile Research Journal, 94(3-4), 508-529.
[37] Tayyaba, N., Younas, T., & Ali, S. (2021). Chemical color stripping of cellulose fabric dyed with reactive dyes. International Journal of Science and Innovative Research (IJESIR), 2(5), 4-16.
[38] Määttänen, M., Asikainen, S., Kamppuri, T., Ilen, E., Niinimäki, K., Tanttu, M., & Harlin, A. (2019). Colour management in circular economy: decolourization of cotton waste. Research Journal of Textile and Apparel, 23(2), 134-152.

the fabric, including reductions in strength, weight, and pilling resistance ratings. Researchers have been exploring methods to minimize fiber damage during dye stripping. For instance, Mu and Yang demonstrated that by controlling solvent use and temperature, they could completely eliminate dispersed, acid, and direct dyes from PET, polyamide 6,6, and cotton fibers, respectively.[39] Recent studies on dye removal have included work that performs the decolorization process of textile fabrics on a pilot scale using an ozone-assisted method. Powar et al. achieved over 90% decolorization of pigment-printed cellulosic textiles with an ozone-assisted approach in an acidic solution.[40] He et al. found that a UV/$Na_2S_2O_4$ photocatalytic system could effectively strip fixed reactive dyes, maintaining relatively high tensile strength in the cotton fibers.[41] Additionally, sequential alkali-acid stripping of reactive dyes from cotton waste has been reported to effectively remove cross-linked textile finishes.

Chemical recycling of cotton fabrics into regenerated fibers presents a promising approach. However, the dissolution of cotton fibers in common solvents is challenging due to the robust intra- and inter-molecular hydrogen bonding found in cellulose macromolecules. The chemical recycling methods for cotton primarily focus on cellulose dissolution, either through polymer dissolution in solvents or the depolymerization of glucose monomers. When utilizing solvents for dissolution, the process can yield either a chemically modified or pure cellulosic fiber product, which can then be used as raw material for producing regenerated or recycled man-made cellulosic fibers. This can be accomplished through various systems, including the Lyocell process, alkali/urea method, or ionic liquid process. Recently, the Lyocell process has emerged as a straightforward physical alternative to the prevalent viscose technology, allowing for the regeneration of cellulosic fibers without generating hazardous by-products such as CS_2, H_2S, and heavy metals. The Lyocell and ionic liquid processes have become the primary technologies studied for the chemical recovery of cellulosic fibers.[42]An overview of chemical recycling of cotton is shown in Figure 11.

Figure 11. An overview of chemical recycling of cotton.[43]

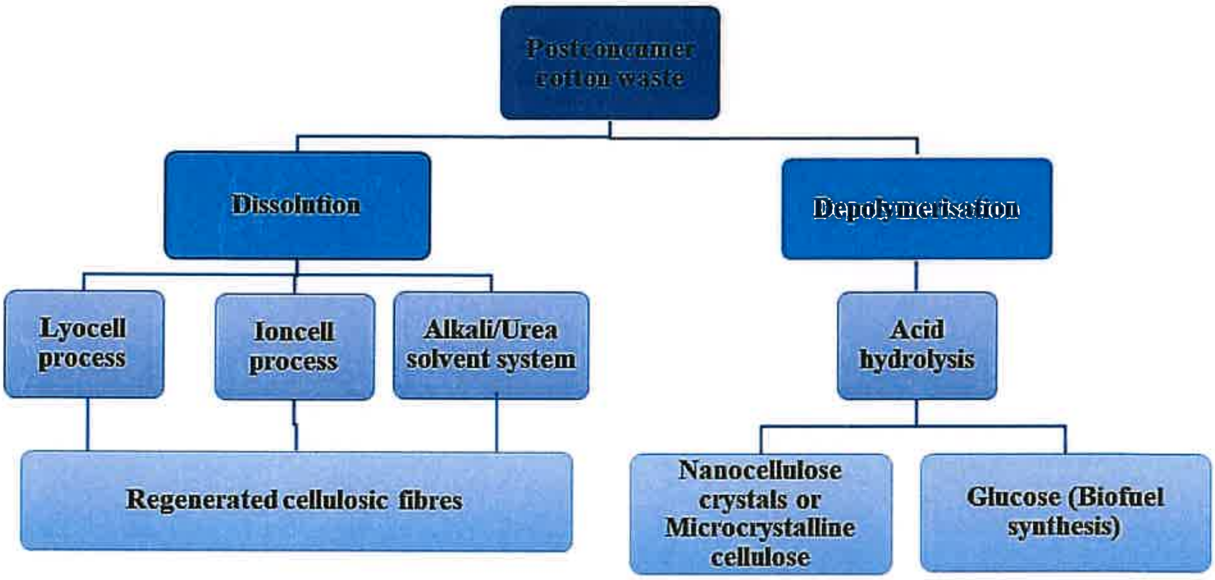
[39]Mu B, Yang Y. Complete separation of colorants from polymeric materials for cost-effective recycling of waste textiles. Chem Eng J 2022; 427: 131570.

[40]Powar, A., Perwuelz, A., Behary, N., vinh Hoang, L., Aussenac, T., Loghin, C., ... & Chen, G. (2021). Investigation into the color stripping of the pigment printed cotton fabric using the ozone assisted process: A study on the decolorization and characterization. Journal of Engineered Fibers and Fabrics, 16, 1558925021992757.

[41]He, Z., Li, M., Zuo, D., Xu, J., & Yi, C. (2019). Effects of color fading ozonation on the color yield of reactive-dyed cotton. Dyes and Pigments, 164, 417-427.

[42]Schuch, A. B. (2016). The chemical recycle of cotton. Revista Produção e Desenvolvimento, 2(2), 64-76.

[43] Le, K. (2018). Textile recycling technologies, colouring and finishing methods. Solid Waste Services. Vancoover, 23-50.



Currently, chemical recycling of wool waste is not widely practiced. Nevertheless, the recovery of wool keratin for applications in biomaterials, adhesives, and resins has been researched and demonstrated on a limited scale. Although successful chemical recycling of wool keratin to produce regenerated protein fibers has not yet been achieved, there have been reports of keratin being extracted from wool fibers.

Wool fiber consists of 82% keratin, which has a notably high cysteine content (10–15%) compared to other sources of keratin.[44] The cysteine in the protein chains is linked through strong disulfide bonds, forming a unique, tightly packed hierarchical structure that results in low solubility for wool keratin. Unlike other keratin structures that feature beta sheets, wool keratin predominantly adopts an alpha helix configuration. Various techniques have been explored to disrupt keratin linkages, including reduction, oxidation, sulfitolysis (or oxidative sulfitolysis), cuprammonium, and ionic liquid reagents. Once the linkages are broken, keratin can be maintained in solution for blending with other materials, allowing for direct spinning. Wet spinning is commonly employed to regenerate keratin fibers mixed with other polymers, while electrospinning has been utilized to produce ultrafine fibers suitable for non-woven textiles.[45]

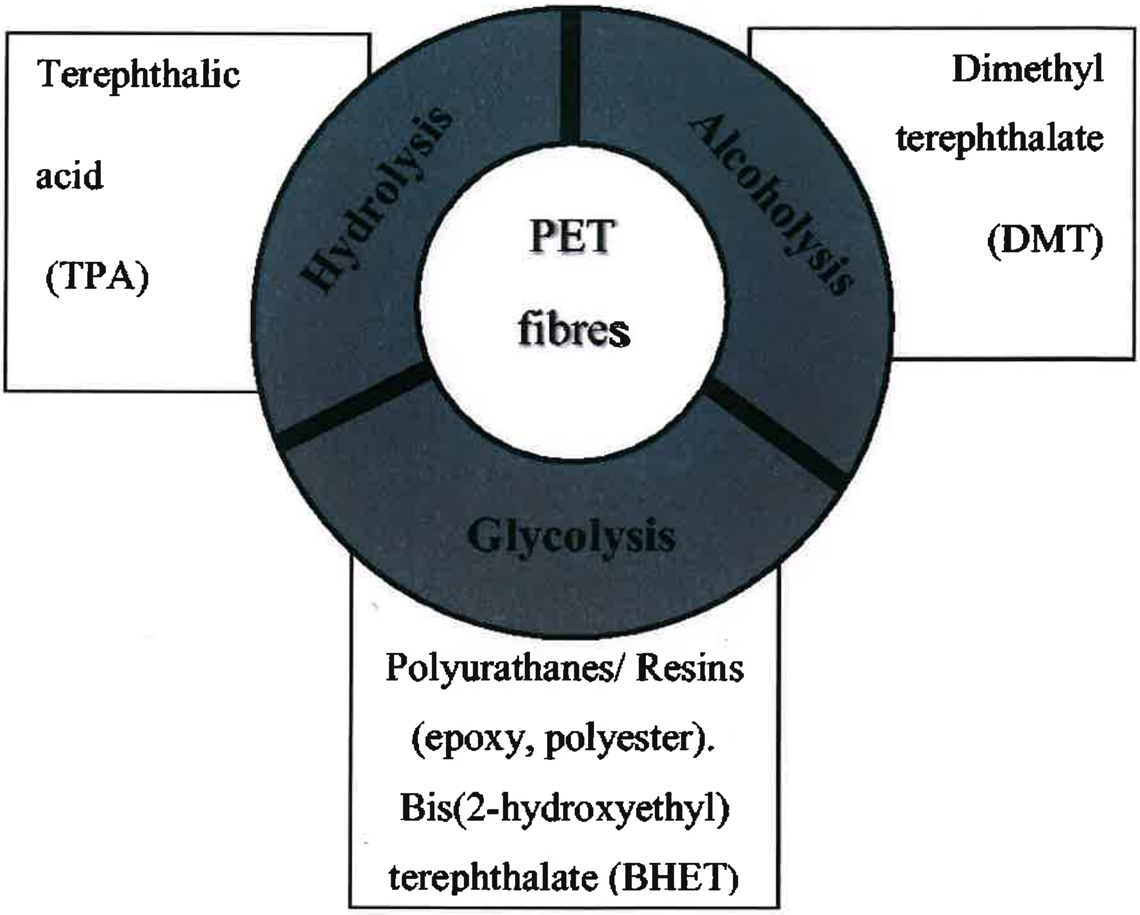
The chemical recycling of polyester through depolymerization has been the focus of extensive research, particularly due to the significant amount of waste generated from PET bottles.[46] These chemical recycling techniques enable the recycling of PET by depolymerizing it into monomers without compromising its quality. The three primary methods for degrading PET are hydrolysis, alcoholysis, and glycolysis. However, only hydrolysis can effectively degrade the PET monomers, terephthalic acid (TPA) and ethylene glycol (EG). Although chemical recycling of PET derived from waste fabrics is not commonly practiced, some researchers have explored this technology. For instance, Li et al. developed a successful approach that combines hydrolysis, reactive processing, and decolorization to transform colored PET fabrics into high-purity TPA.[47]

A major drawback of chemical recycling for PET is that these methods necessitate high-pressure and high-temperature conditions, along with the use of toxic degrading agents for the

[44]Wang, Q., Zhang, L., Wang, Q., Liu, Y., & Zhu, P. (2020). Study on dissolution and recovery of waste wool by sodium sulfide system. Ferroelectrics, 562(1), 114-124.
[45]Goyal S, et al. Extraction of keratin from wool and its use as biopolymer in film formation and in electrospinning for composite material processing.
[46]Geyer, B., Lorenz, G., &Kandelbauer, A. (2016). Recycling of poly (ethylene terephthalate)–A review focusing on chemical methods. Express Polymer Letters, 10(7), 559-586.
[47]Li, Y., Yi, H., Li, M., Ge, M., & Yao, D. (2022). Synchronous degradation and decolorization of colored poly (ethylene terephthalate) fabrics for the synthesis of high purity terephthalic acid. Journal of Cleaner Production, 366, 132985.

depolymerization process. Additionally, these methods typically require purification and separation steps for product recovery, leading to potential environmental hazards. In contrast, mechanical recycling is less energy-intensive and demands fewer resources than chemical recycling, resulting in lower overall costs. The technical infrastructure requirements for mechanical recycling are also minimal, as this process is well-established compared to the emerging, technically challenging, and economically unfeasible chemical methods. Mechanical recycling shreds plastic waste without the use of toxic chemicals, such as acids and solvents, for dissolution. Therefore, mechanical recycling is often the preferred method for handling PET.Recycling technologies related to PET recycling are shown in Figure 12.

Figure 12. Technologies for PET recycling.[48]



[48]Baloyi, R. B., Gbadeyan, O. J., Sithole, B., & Chunilall, V. (2024). Recent advances in recycling technologies for waste textile fabrics: A review. Textile Research Journal, 94(3-4), 508-529.

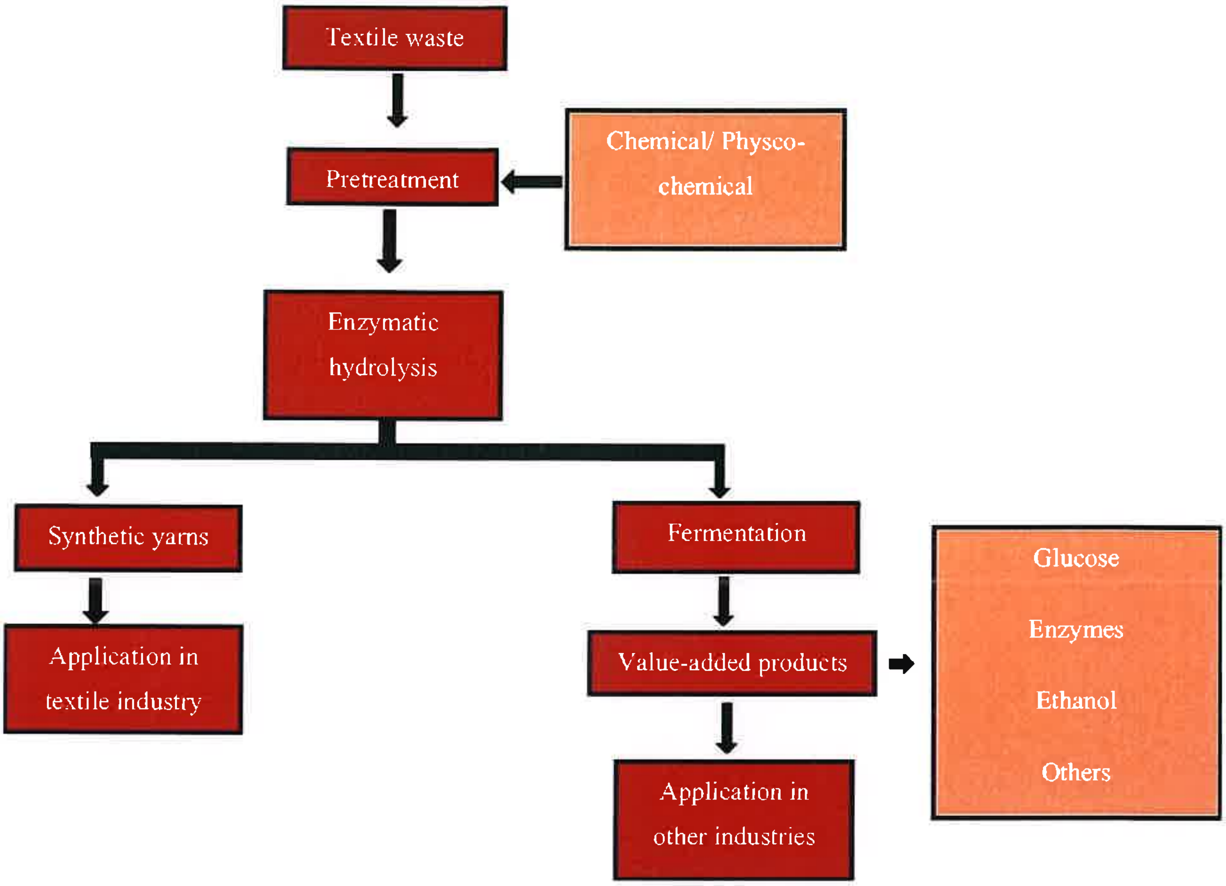
Recycling polymers through melting and spinning into new textile fibers is often challenging due to contamination, which makes monomer recycling the only viable option for blended textiles. Blended fabrics usually comprise hydrolysable synthetic fibers, such as polyacrylics, polyesters, and polyamides, alongside natural fibers like cotton and wool. The commercial development of chemical recycling for waste textile fabrics is limited due to the complexity of the material's components, necessitating expensive separation processes to extract synthetic polymers from natural fibers. Additionally, various pre-processing steps are required to eliminate chemicals and contaminants from the fabric waste, further driving up costs. As a result, pyrolysis for producing liquid fuels is not a preferred method, largely due to the high oxygen content found in the biomass of natural fibers.

3.4. Biochemical Recycling

Enzymes can be employed to depolymerize end-of-life textiles into their monomeric building blocks, which can subsequently be utilized in the creation of value-added products such as glucose and bioethanol. One of the key advantages of biological processes is their generally low energy requirements, reliance on benign solvents and chemicals, and utilization of renewable resources instead of fossil fuels. Additionally, this method is highly selective, making it an effective option for separating blended textile waste. However, this technology is limited to natural polymers, tends to be expensive, and has slower reaction times compared to chemical recycling.[49]Cellulase enzymes capable of hydrolyzing cellulose-based textile materials into sugars have been developed through solid-state fermentation. Figure 13 illustrates various value-added products that can be produced from cellulosic waste via biochemical recycling.

Figure 13. Biochemical recycling process.[50]

[49]Harmsen, P., Slottje, C., Baggerman, M., &Sillekens, E. (2021). Biological degradation of textiles: and the relevance to textile recycling (No. 2220). Wageningen Food & Biobased Research.
[50]Baloyi, R. B., Gbadeyan, O. J., Sithole, B., & Chunilall, V. (2024). Recent advances in recycling technologies for waste textile fabrics: A review. Textile Research Journal, 94(3-4), 508-529.



In theory, biochemical recycling has the potential to naturally eliminate textiles from the environment. However, the current mix of fibers predominantly comprises synthetic materials, with natural polymers present to a lesser extent, which are more amenable to biological degradation. As a result, the practical application of this technology is still limited. Currently, there are no commercial operations for biochemical recycling of textile fabrics.

4. TEXTILE RECYCLING IN FINLAND

Textile waste management is an increasing priority for Finland, in line with the country's sustainability objectives and European Union regulations. The textile industry is a significant contributor to environmental degradation, with high resource consumption, pollution, and waste generation. To mitigate these issues, Finland has taken proactive measures to establish a circular economy framework that prioritizes recycling,. reuse, and sustainable production. Government initiatives, corporate responsibility programs, and consumer awareness campaigns all play vital roles in improving textile recycling practices.The transition towards a more sustainable textile sector in Finland involves multiple stakeholders, including government agencies, private corporations, non-governmental organizations (NGOs), and consumers.

Textile consumption in Finland has remained relatively stable over recent years, with an annual per capita consumption of approximately 11.3 kg, according to the Finnish Environment Institute.[51]The concept of supply chain, which emerged as a result of these needs, has been defined in many ways to date. The distribution of textile consumption in Finland by category is given in Table 1.

Table 1: The distribution of textile consumption in Finland[51]

Textile Type	Consumption per Capita (kg)
Clothing	7.2
Household Textiles	4.1
Industrial Textiles	2.5

As seen in the table, the breakdown of textile consumption by category highlights that clothing accounts for the largest share, followed by household textiles and industrial textiles.The consumption of textiles is influenced by multiple factors, including seasonal changes, fashion trends, and increasing consumer awareness regarding sustainability. Finland has seen a rise in second-hand clothing purchases and the adoption of slow fashion, which aims to reduce excessive textile production and consumption.Consumer behavior studies indicate a growing demand for sustainable fashion, with increased interest in second-hand markets, rental services, and clothing repair initiatives. The Finnish government has also encouraged ethical purchasing through incentives for sustainable brands and increased awareness about the environmental impact of fast fashion. Additionally, large-scale fashion retailers have introduced take-back programs, allowing consumers to return old textiles for recycling.[51]

In 2019, Finland's total textile consumption was approximately 130 million kilograms, with households accounting for 53% and industries for 47%. On average, each Finn consumed 11.3 kilograms of new clothing and home textiles annually. The same year saw 85,770 tons of end-of-life textiles, with 82% remaining in Finland for reuse or recovery and the remaining 18% exported. Notably, around 60% of these end-of-life textiles were incinerated with mixed waste, underscoring the need for improved recycling measures.[52]Textile waste figures for Finland are given in Table 2.

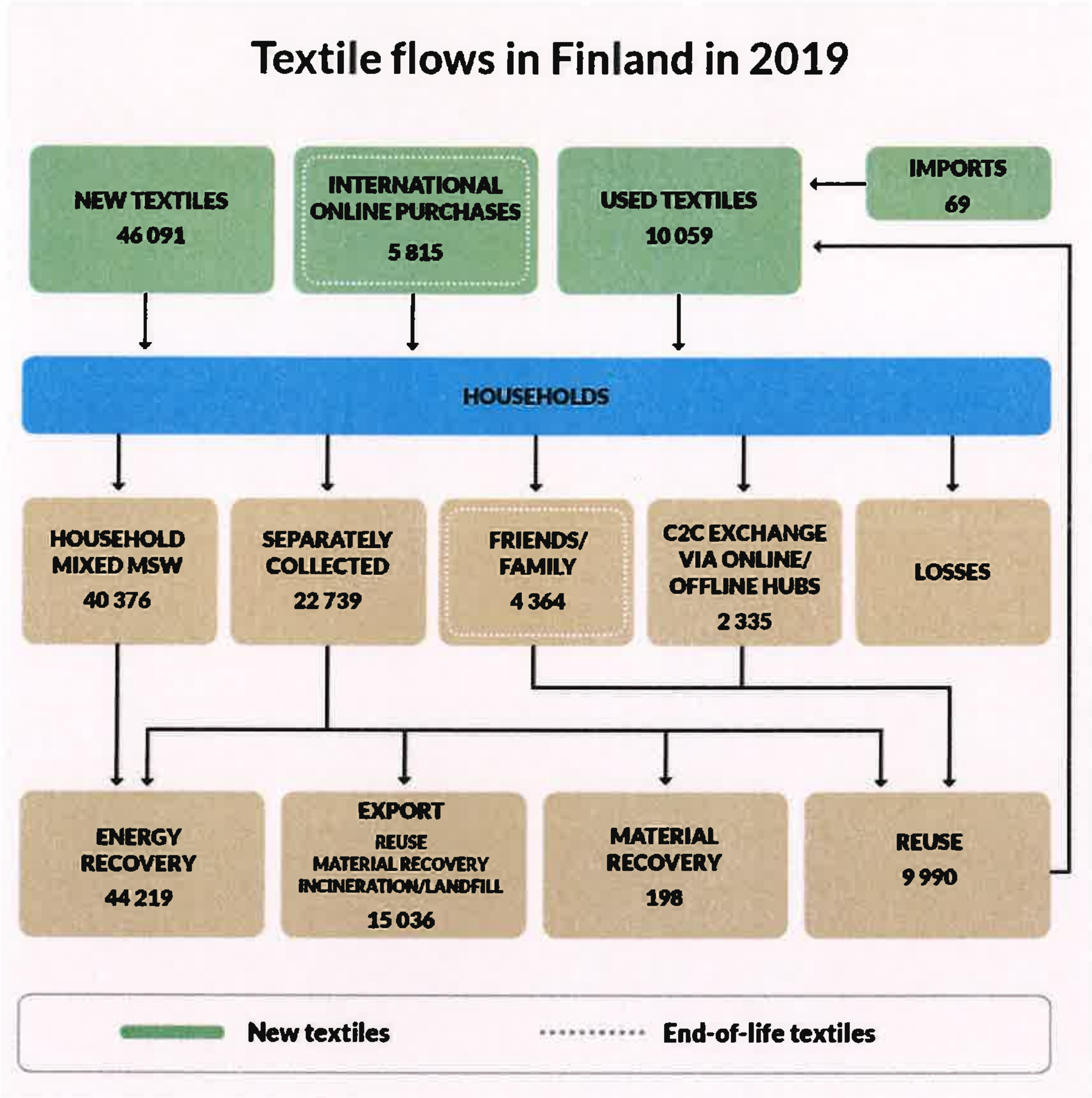
Table 2: Textile waste amounts for Finland[51]

Waste Category	Amount (tons)	Percentage (%)
Reusable Textiles	18,870	22%
Incinerated Textiles	51,462	60%
Recycled Textiles	10,292	12%
Landfilled Textiles	5,146	6%

As given in the table, this waste is managed through various methods, including reuse, incineration, recycling, and landfilling.Incineration remains the dominant method for textile waste disposal, raising concerns about its environmental impact, particularly carbon emissions. However, Finland is actively working to improve recycling infrastructure and promote alternative waste management solutions, such as increasing the use of mechanical and chemical recycling techniques.The textile cycle in Finland is given in Figure 14.

[51]Finnish Environment Institute (SYKE). (2022). Textile Consumption and Waste Management Report. Retrieved from https://www.syke.fi.
[52]Dahlbo, H., Rautiainen, A., Savolainen, H., Oksanen, P., Nurmi, P., Virta, M., &Pokela, O. (2021). Textile flows in Finland 2019.

Figure 14. Textile flows in Finland.[53]



The key contributors to textile waste generation in Finland include:

- **Fast fashion and mass production**: Rapidly changing trends lead to increased disposal of garments.
- **Limited consumer awareness**: Many consumers still discard textiles instead of opting for reuse or recycling.
- **Lack of convenient recycling infrastructure**: While textile recycling centers exist, accessibility can be a challenge in rural areas.
- **Product durability and composition**: Non-recyclable mixed-fiber textiles increase landfill contributions.[54]

Finland has been steadily increasing its focus on sustainable waste management through policy reforms, infrastructure improvements, and consumer engagement strategies. Several key trends have emerged:

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[53]Helena Dahlbo, Aija Rautiainen, Hannu Savolainen ym (2021): Textile flows in Finland 2019. Reports from Turku University of Applied Sciences 276, 2021.
[54]Finnish Ministry of the Environment. (2023). National Sustainability and Circular Economy Strategy. Helsinki: Ministry of the Environment.

- **Growth in separate textile waste collection**: The implementation of specialized collection points has improved sorting efficiency and increased the volume of textiles diverted from landfills.
- **Increase in textile reuse and resale**: Platforms for second-hand clothing sales, rental fashion models, and textile repair services have gained popularity, reducing demand for new textile production.
- **Investment in textile-to-textile recycling**: Advances in fiber recycling technology have enabled the conversion of used textiles into raw materials for new products, reducing reliance on virgin resources.[53]

4.1. Finland's Textile Recycling Infrastructure

Under EU legislation, member states are required to establish a separate textile collection system by January 2025. However, Finland has taken a proactive approach by passing a law in 2021 mandating municipalities to begin separate textile collection as early as January 2023. Responsibility for managing household textile waste falls under municipal waste management authorities. Some municipalities in Finland have piloted and implemented separate textile collection systems ahead of the mandated schedule.[55]

The Helsinki Region Environmental Services (HSY) initiated collection pilot programs in 2019 to assess and develop various textile waste collection strategies. Since then, HSY has continued to refine and expand its collection network, testing different methods to ensure efficiency and accessibility.To comply with the EU's directive on separate textile waste collection by 2025, Finland introduced an organized textile collection and sorting system in 2023.[56]The core components of this system include:

- Establishment of municipal textile waste collection centers across major cities and rural areas (Finnish Ministry of the Environment, 2023).
- Retailer-led collection programs that encourage consumers to return old clothing in exchange for discounts or store credits (SYKE, 2022).
- Expansion of donation-based textile reuse initiatives through charities, non-profits, and social enterprises (Nordic Council, 2021).
- Development of AI-assisted sorting facilities to improve efficiency in textile waste categorization and recycling.

The collection of end-of-life textiles in Finland is primarily managed by charity organizations such as UFF, the Salvation Army, the Finnish Red Cross, and Fida. These entities have established collection points across the country, often located near Rinki Eco Take-Back points or within urban areas like supermarkets. In 2019, approximately 44% of household end-of-life textiles were separately collected, yet a significant portion still ended up in incineration plants.[57]

To enhance sorting efficiency, Helsinki Region Environmental Services (HSY) collects dry, unusable clothing and household textiles, which are then transported to waste service centers for pre-sorting. Subsequently, these textiles are sent to facilities like Lounais-SuomenJätehuolto Oy (LSJH) in Turku for further processing. LSJH has initiated a pilot-phase processing plant as part of the Telaketju project, aiming to mechanically refine end-of-life textiles into recycled fiber.[55]

Charity organizations play a pivotal role in the reuse of textiles. For instance, in 2020, UFF reported that 95.5% of their textile donations were either reused or repurposed as material. About 80% of these textiles were distributed to wholesalers in Finland, the Baltic countries,

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[55]Dang, T. T. T. (2023). Circular Economy Implementation into the Clothing and Household Textiles in Finland: planning the Reuse Practices to Meet the Specific Objectives of the LIFE IP CIRCWASTE Finland Project.
[56]European Commission. (2022). EU Circular Economy Action Plan: European Union Policy on Waste Management. Publications Office of the European Union.
[57]Heikkilä, P., Heikkilä, J., Kamppuri, T., Keskisaari, A., Määttänen, M., Saarimäki, E.,& Harlin, A. (2024). Technologies and Model for Sustainable Textile Recycling.

Russia, and Asia, where they were further processed or sold. In terms of material recovery, municipal waste management companies began separate collections of end-of-life textiles in 2019, amassing 213 tones that year and 416 tons in 2020. Additionally, industries such as hotels, restaurants, and hospitals, which primarily utilize textile rental services, discarded approximately 1,330 tons of textiles in 2019. Of this, 67% was incinerated, 32% recycled, and 1% reused.[56]

The largest textile recycling facility in the Nordic region, located in Paimio, Finland, plays a central role in textile waste management. This facility, operated by Rester Oy and Lounais-SuomenJätehuolto (LSJH), has the capacity to process up to 12 million kg of textiles per year.[58]The Paimio facility focuses on mechanical and chemical textile recycling methods. The mechanical process involves shredding textiles into fiber material for reuse in insulation, automotive products, and industrial textiles. Meanwhile, chemical recycling breaks down textiles into raw materials for producing new fabric, significantly reducing the need for virgin fibers.

4.2. Finland's Future Outlook and Challenges

Current projections suggest that Finland's textile recycling rate will rise from 12% to 40% by 2030, driven by policy incentives, infrastructure investments, and public engagement campaigns year.[59]A national strategy for achieving a circular economy in textiles includes:

- **Enhancing consumer education** on responsible textile disposal and sustainable shopping.
- **Scaling up textile sorting and recycling plants** to accommodate increased waste collection.
- **Advancing textile recycling technologies**, such as enzymatic and fiber-to-fiber recycling.
- **Strengthening collaborations between industries and policymakers** to create a closed-loop textile supply chain.

Finland has launched several initiatives to bolster textile recycling:

- **Telaketju Project**: A collaborative effort involving various stakeholders, the Telaketju project focuses on developing an extensive ecosystem for textile recycling. It encompasses aspects like business models, consumer behavior, sustainable materials, product design, and recycling technologies.[60]
- **Paimio Pilot Plant**: In February 2021, the first large-scale textile waste-processing plant in the Nordics commenced operations in Paimio, Finland. A joint venture between a private company and a municipal waste management organization, the plant aims to process 12,000 tons of textile waste annually, representing about 10% of Finland's textile waste.[61]
- **Lahti Incentive Scheme**: The city of Lahti implemented a pilot incentive scheme offering residents vouchers for local services in exchange for recycling textiles. This initiative led to a remarkable 500% increase in textile recycling rates, demonstrating the effectiveness of incentive-based approaches.[62]

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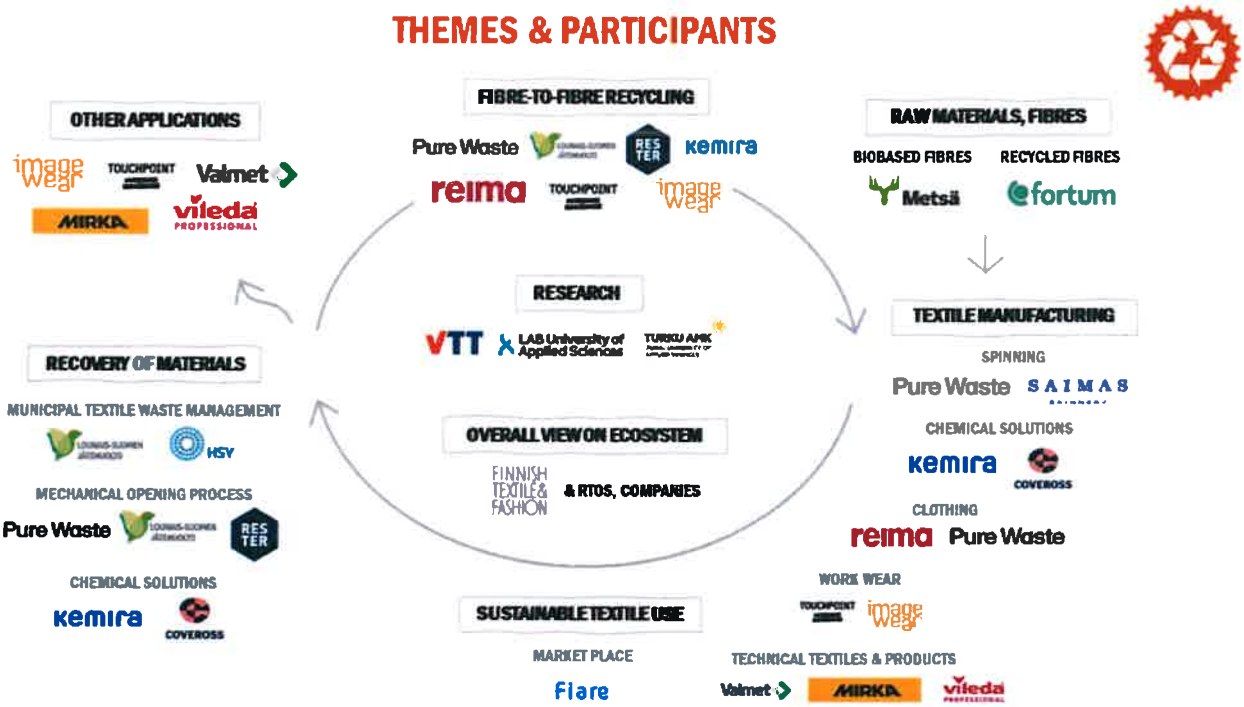
[58]Rester Oy &Lounais-SuomenJätehuolto (LSJH). (2023). Textile Recycling Facility Reports. Retrieved from https://www.rester.fi.
[59]Chioatto, E., &Sospiro, P. (2023). Transition from waste management to circular economy: the European Union roadmap. Environment, Development and Sustainability, 25(1), 249-276.
[60] https://telaketju.turkuamk.fi/en/about-telaketju/.
[61] https://www.hanken.fi/en/news/new-research-explores-efficient-methods-recycling-unusable-clothing.
[62] https://www.lahti.fi/en/news/swap-in-your-old-towels-for-pool-passes-recycling-rate-goes-up-500-as-lahti-pilots-an-incentive-system-for-used-textiles/.

- The vision of **Telavalue BF** project was to solve sustainability and waste problems related to current textile system through circular economy[63].

Telavalue was Business Finland Co-Innovation project which consisted of the public research project and six company projects (Figure 15). The main objectives of the public research project were

- to support and build value chains for sustainable production, use and cycles of textiles
- combine recycled and novel bio-based fibres as basis for sustainable Finnish textile production
- ensure efficient product use via circular design and novel business models
- ensure efficient textile material circulation via recycling of different kinds of discarded textiles from households as well as companies including also technical textiles.

Figure 15. Televalue BF project[63]



Despite Finland's progress in textile recycling, several challenges remain[64]:

- **Public awareness and participation**: Encouraging widespread adoption of recycling practices is an ongoing effort.
- **Limited processing capacity**: Current facilities must expand to handle the increasing volume of textile waste.
- **Recycling technology advancements**: Innovations are needed to improve fiber recovery rates and material quality.
- **Industrial adoption of recycled fibers**: Encouraging more companies to integrate recycled materials into their supply chains is crucial for sustainability (Nordic Council, 2021).

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[63] Heikkilä, P., Arvez, E., Hannula, S., Heikinheimo, L., Heinonen, E., Hokkanen, M., .&Kamppuri, T. (2024). Towards Sustainable Textile System with Telavalue.
[64] Munkholm, L., Lindberg Laursen, B., Christensen, A. C., Trab Munk Christensen, A., Slater Christensen, B., Dam Larsen, J., & Tønder, R. A. (2023). Mapping Sustainable Textile Initiatives in the Nordic Countries. Nordic Council of Ministers.

- **High production costs**: The cost of recycling textiles remains higher than producing new textiles, which discourages widespread adoption in the industry.

Finland has made considerable progress in textile recycling through structured policies, improved infrastructure, and technological advancements. However, achieving a fully circular textile economy requires continued investments, innovation, and collaboration among stakeholders. By integrating sustainable solutions, expanding recycling facilities, and promoting consumer engagement, Finland is setting an example for other nations in textile waste management. The future of textile recycling in Finland looks promising, with an increasing shift towards sustainability, legislative support, and industry commitment to reducing waste.

5. TEXTILE RECYCLING IN PAIMIO

Paimio is a townin southwestern Finland with a population of about 11,100 and is located along the E18 highway between Turku and Helsinki. With an area of 240.02 km², Paimio has been a town since January 1, 1997. The landscape in Paimio is fertile and much more than the seabed. Its flatness is broken by open rocky forest areas - even the basic landscape of Finland. Paimio is also proud of its river valley, which has been named a national cultural landscape. Paimio is a lively rural town that has been able to develop its level of service well according to the requirements of the time. At the same time, it has taken good care of the well-being of its residents as a safe and stimulating home district remain.[65]

Textile waste has become a critical issue worldwide, with millions of tonnes ending up in landfills annually. Finland, a leader in sustainable waste management, has taken significant steps to mitigate this problem. The town of Paimio has emerged as a key player in textile recycling, housing the Nordic region's first industrial-scale textile refinement plant. The establishment of a large-scale textile refinement plant in Paimio marks a significant advancement in sustainable waste management practices.[66]

Established in 2021, the Paimio textile refinement plant represents a major step forward in Finland's sustainability efforts.[67] Operated by Rester Oy in collaboration with Lounais-SuomenJätehuolto Oy (LSJH), the facility is designed to process up to 12,000 tonnes of end-of-life textiles annually (Figure 16). This capacity accounts for over 10% of Finland's total textile waste.[66]

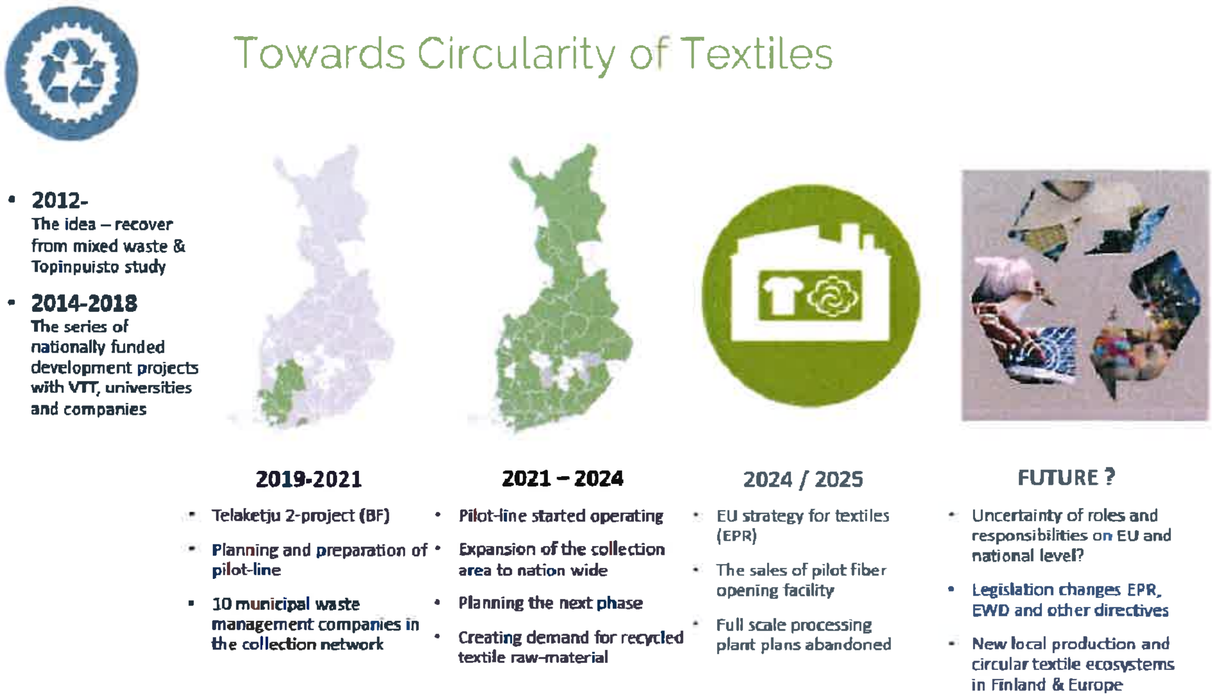
Figure 16. Lounais-Suomen Jätehuolto Oy[67]

The plant specializes in recycling textiles from both households and businesses. Household waste is managed by LSJH, while Rester Oy focuses on industrial and commercial textile waste.

[65]https://www.paimio.fi/en/city-and-administration/.
[66]Yle News. (2021). Nordics' biggest textile recycling centre opens in Finland. Retrieved from https://yle.fi/a/3-12172022.
[67]Lounais-SuomenJätehuolto. (2021). First large-scale end-of-life textile refinement plant in Finland. Retrieved from https://www.recycling-magazine.com.

The facility uses advanced mechanical recycling processes to convert old textiles into raw materials for new applications.[68] This model aligns with Finland's circular economy goals, reducing dependency on virgin resources while minimizing environmental harm (Figure 17).

Figure 17. Finland's Textile Circularity Plan [67]



The Paimio plant spans approximately 3,000 square meters and utilizes state-of-the-art mechanical recycling technology (Figure 18).[67] The process begins with the collection and sorting of textiles, where materials are categorized based on fiber composition and potential end-use.

Figure 18. Paimio's Textile Circularity Plant [67]

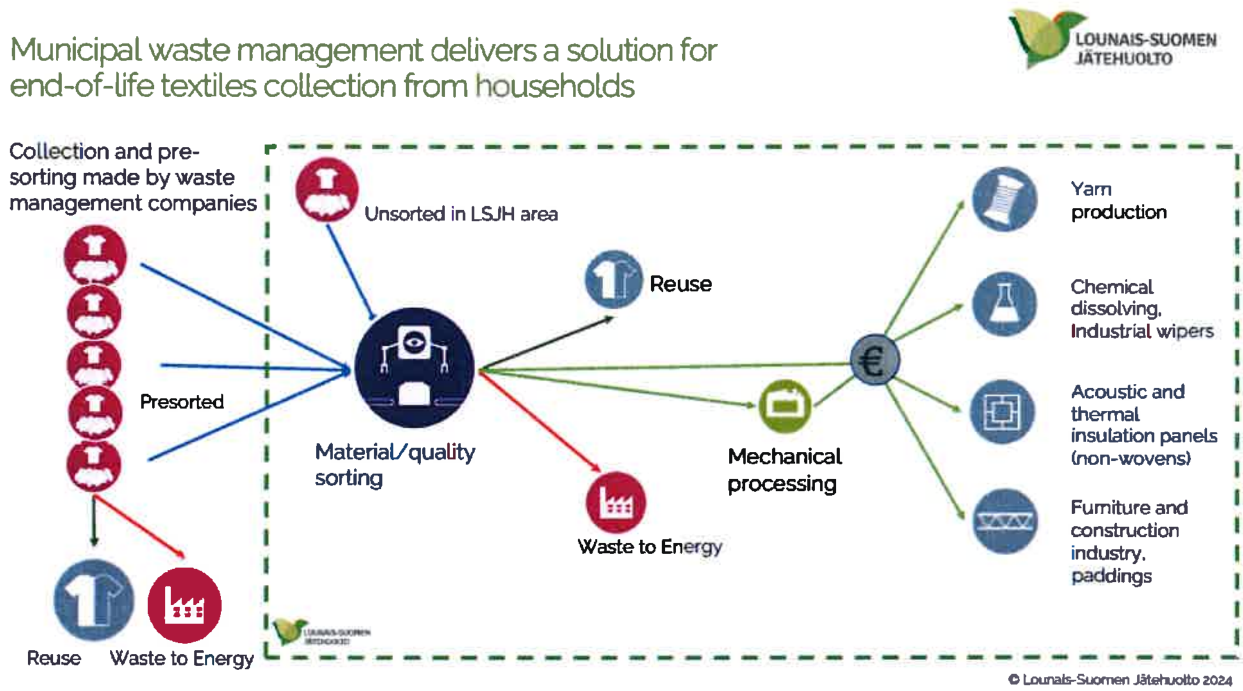
[68]Hanken School of Economics. (2023). New research explores efficient methods for recycling unusable clothing. Retrieved from https://www.hanken.fi/en/news.

The recycling process consists of several key steps:

1. **Collection and Sorting** – Textiles are collected through municipal programs and business partnerships. Advanced sorting techniques help separate usable materials from non-recyclable items.[66]
2. **Shredding and Fiberization** – Textiles are shredded into smaller pieces before being transformed into fibers suitable for industrial applications.[68]
3. **Material Reuse** – The processed fibers are used to manufacture insulation materials, nonwoven fabrics, composites, and even new textiles.[67]
4. **Quality Control and Distribution** – The final products undergo rigorous quality control before being supplied to various industries.[66]

This process significantly reduces textile waste while supporting industries in need of sustainable raw materials.This recycling processes are shown in Figure 19.

Figure 19. Paimio's Textile Circularity Plant[69]



One of the main benefits of the Paimio textile recycling initiative is its positive impact on the environment. By diverting textiles from landfills and incineration, the plant contributes to reduced carbon emissions and lower resource consumption.[70]

A comparative analysis of the environmental benefits of textile recycling in Paimio shows:

- **Reduction in Greenhouse Gas Emissions** – The recycling process prevents textile incineration, a major contributor to CO_2 emissions (Lounais-SuomenJätehuolto, 2021).[67]
- **Water and Energy Savings** – Recycled textiles require significantly less water and energy compared to producing virgin materials (Yle News, 2021).[66]
- **Decreased Landfill Usage** – Textile waste takes years to decompose in landfills, and recycling helps alleviate this burden (Hanken School of Economics, 2023).[68]

[69]https://poistotekstiili.lsjh.fi/en/home/.
[70]Dang, T. T. T. (2023). Circular Economy Implementation into the Clothing and Household Textiles in Finland: planning the Reuse Practices to Meet the Specific Objectives of the LIFE IP CIRCWASTE Finland Project..

Furthermore, the initiative aligns with Finland's national waste management strategy, which aims for a 50% recycling rate for textiles by 2030[71]. Two scenarios have been prepared for different waste volume developments for the municipal waste facility capacity requirement. These scenarios take into account the recycling targets for municipal waste (55%) and biological waste (60%) until 2023 put forward in this plan (Table 3).

Table 3: Municipal waste treatment volumes in 2015 and estimates of treatment needs to 2023 based onthe recycling targets in the Waste Plan[71]

	2015	Waste quantity scenarios 2023	
		Level of 2015	Moderate growth waste quantity forecast
Total waste quantity / waste quantity estimates (1000 t)	2738	2738	2947
Recyling (biowaste included)	**1095**	**1506**	**1621**
Biological treatment	329	510	549
Need for additional capacity in biological treatment	**-**	**181**	**220**
Other recycling (excluding biowaste)	767	996	1072
Need for additional capacity in other recycling	**-**	**229**	**305**
Energy recovery	1314	1095	1179
Landfilling	**301**	**137**	**147**

The first scenario uses waste volumes in 2015 as reported in waste statistics. The scenario assumes that waste production has been successfully stopped at 2015 levels. The second scenario uses the medium waste volume growth forecast to 2023 of the Waste Volume Forecast, which models future municipal waste volumes.

Taking into account recycling targets, the additional capacity needed for biological treatment of municipal waste will be approximately 180,000 - 220,000 tonnes. This is equivalent to building 3-4 new plants of the same size as the biogas plant of the Helsinki Regional Environmental Services Authority HSY. Additional treatment capacity of 200,000 - 300,000 tonnes is needed for other recyclable municipal waste. In particular, the treatment of plastics and also to some extent fibre packaging will require additional capacity. Increased recycling of low-volume waste such as textiles may also be necessary to increase the overall recycling rate. The need for energy recovery capacity for municipal waste is estimated at 1,100,000 - 1,200,000 tons. The need for storage will drop to 140,000 - 150,000 tons, meaning that 5% of all municipal waste generated will go to landfill.[71]

Despite its success, the Paimio textile recycling plant faces several challenges:

- Scaling Up Operations – Although the plant processes 12,000 tons of textile waste annually, this represents only a fraction of Finland's total textile waste (Yle News, 2021).
- Consumer Participation – Increasing public awareness and accessibility of textile recycling facilities remains crucial (Hanken School of Economics, 2023).
- Market Development for Recycled Textiles – Creating demand for recycled materials in various industries is essential for the long-term sustainability of the initiative (Lounais-SuomenJätehuolto, 2021).

[71]Laaksonen, J., Salmenperä, H., Stén, S., Dahlbo, H., Merilehto, K., &Sahimaa, O. (2018). From recycling to a circular economy The National Waste Plan 2030.

Future directions for textile recycling in Paimio include expanding collection networks, investing in advanced sorting technologies, and fostering collaborations with international partners to create a more sustainable global textile supply chain[72].

The Paimio textile refinement plant is a pioneering initiative in Finland's journey toward a circular economy. By processing significant amounts of textile waste and repurposing it into industrial materials, the facility exemplifies the potential of innovative waste management strategies. However, continued investment, policy support, and public engagement are necessary to scale up these efforts and maximize their impact.

As Finland continues to lead in sustainability, Paimio's model of textile recycling serves as an example for other regions seeking to implement similar initiatives. With continued advancements, the town is set to play a crucial role in shaping the future of textile waste management.

The establishment of the textile refinement plant in Paimio suggests a supply chain that includes:

- Inbound Logistics: Collection of end-of-life textiles from various sources, possibly extending beyond Paimio to other regions in Finland.
- Processing: Utilization of advanced recycling technologies to convert waste textiles into reusable materials.
- Outbound Logistics: Distribution of recycled textile fibers to industries for the production of new products.

This supply chain emphasizes sustainability and aligns with broader environmental goals.

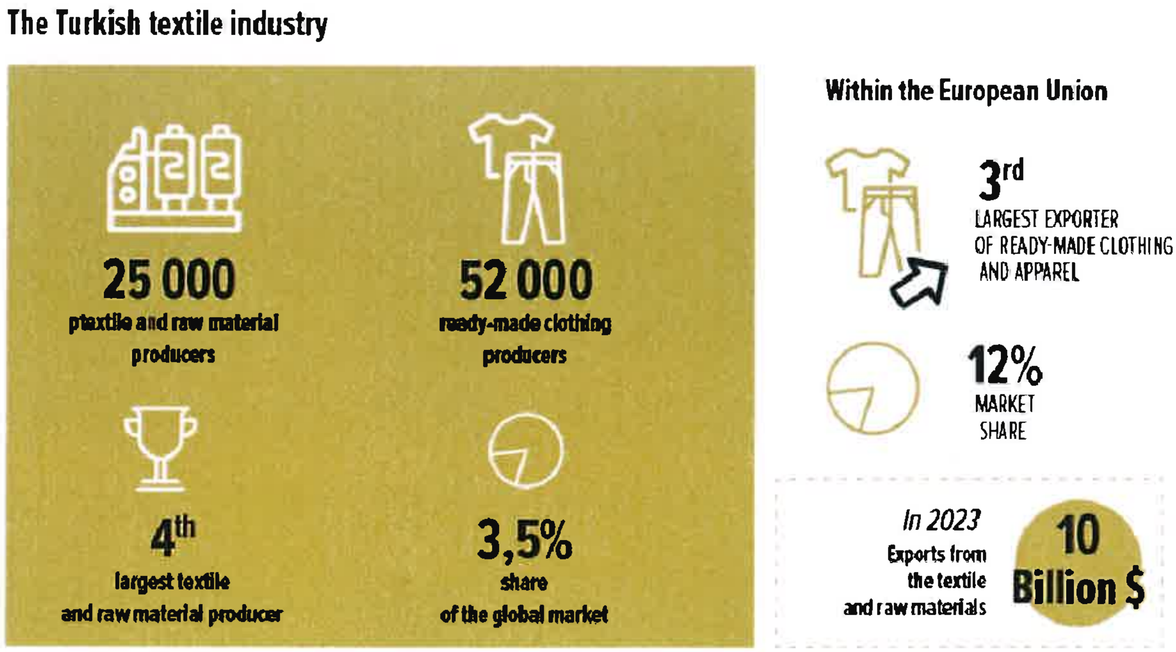
Paimio's role in textile recycling indicates a structured supply chain focused on sustainability. Continued investment in infrastructure and market development will be crucial for optimizing this supply chain and achieving long-term economic and environmental benefits.

[72]Hinkka, V., Aminoff, A., Palmgren, R., Heikkilä, P., & Harlin, A. (2023). Investigating postponement and speculation approaches to the end-of-life textile supply chain. Journal of cleaner production, 422, 138431..

6. TEXTILE RECYCLING IN TURKEY

Turkey's textile and apparel sectors are pivotal to its economy, accounting for 8.8% of the manufacturing industry's production value and 9.9% of its value-added. The industry encompasses a broad spectrum, from fiber preparation to finished consumer goods, including apparel, home textiles, and technical textiles.[73] Acording to the Turkish Exporters Assembly (TIM), Turkey's textile industry—encompassing both textile/raw materials and ready-made clothing/garments—boasts an integrated production system that is rarely seen on a global scale. With 25,000 textile and raw material producers and 52,000 ready-made clothing manufacturers, Turkey remains a dominant player in international markets (Figure 20). The country ranks as the world's fourth-largest producer of textiles and raw materials and the fifth-largest exporter of ready-made clothing and apparel, holding a 3.5% share of the global market.Within the European Union, Turkey secures its position as the third-largest exporter of ready-made clothing and apparel, commanding a 12% market share. Despite the economic challenges of 2023, the textile sector continued to be a key driver of Turkey's exports, ranking third in total export volume after the automotive and chemical industries. However, Turkey's ready-made clothing and apparel exports declined by 9.2% compared to 2022, totaling $19.3 billion. Notably, 59.9% of sector-specific exports were directed toward EU countries, with Germany, the Netherlands, Spain, the UK, and France being the top destinations.Additionally, global exports from Turkey's textile and raw materials sector were projected to reach $10 billion in 2023, with Italy, Germany, the US, Spain, and the UK among the primary export markets. Looking ahead to 2024, Turkey aims to break new export records—particularly in the ready-made clothing and apparel sector—by leveraging export-supportive policies, fiscal discipline, and strategic economic measures to achieve a $20 billion export target.[74]

Figure 20. Turkish Textile Industry[74]



[73]Sectoral Roadmaps: Textile Sector in Turkey. (2021). Turkey Resilience Project inResponse to the Syria Crisis (TRP). Retrieved from https://www.undp.org/sites/g/files/zskgke326/files/migration/tr/Sectoral_Roadmaps_Textile_Sector_in_Turkey-re2.pdf
[74]Special Report for Turkey. (2024). Premiere Vision SA. Retrieved from https://www.premierevision.com/en/topic/special-report-turkey/

In the Turkish textile sector; Istanbul, Bursa, Gaziantep, Kahramanmaras, Usak, Izmir, Denizli, Adana and Tekirdag are seen as the prominent provinces; Kahramanmaras, Istanbul, Gaziantep, Usak and Bursa yarn production, Denizli towel, bathrobe, home textile manufacturing, Usak blanket and recycling, Tekirdag (Corlu and Cerkezkoy) finishing, Adana cotton weaving and finishing, Gaziantep polypropylene, nonwoven surface and machine carpet making, Istanbul stands out as the concentration area in garment and knitting production.[75]

According to 2020 TUIK data, 78.3 million tons of 127.4 million tons of waste processed in waste disposal and recovery facilities in Turkey were disposed of and 49.1 million tons were recovered. The total amount of processed waste increased by 22% compared to 2018.The total capacity of the sanitary landfills was determined as 1.2 billion m3. 77.8 million tons of waste, 31.9 million tons of which is hazardous, was disposed of in a total of 174 landfills.Energy recovery was achieved by burning 1.3 million tons of waste in co-incineration facilities with waste recovery licenses. Except for compost and co-incineration facilities, a total of 47.6 million tons of metal, plastic, paper, mineral, etc. waste was recovered in other licensed waste recovery facilities. In Turkey, approximately 1.8 million tons of textiles are consumed annually, with about 650,000 tons becoming waste. However, only around 40,000 tons of this waste are collected, and a significant portion, approximately 30,000 tons, ends up in landfills.Turkey, with a share of 18.6% in the world in Export of Recycled Cotton Fiber, is also the top exporting country.Regenerated yarns, knitted fabrics, woven fabrics, clothing and socks obtained from recycled fibers are exported to 62 countries.[76]

The Turkish government has initiated programs aiming to incorporate at least 30% recycled materials in new clothing by 2030 and to halve the environmental footprint of the textile sector by 2035. These initiatives align with global trends emphasizing sustainability and circular economy principles.[77]The textile recycling sector in Turkey faces challenges such as material complexity, potential loss of quality during recycling processes, and economic feasibility. The diverse composition of textile materials complicates recycling efforts, and mechanical processes can degrade fiber quality. Additionally, high costs and inadequate infrastructure pose significant hurdles.Advancements in recycling technologies, including more efficient mechanical and chemical methods, are improving the quality and range of materials that can be recovered. Investments in recycling infrastructure have increased, leading to the establishment of new facilities and upgrades to existing ones.[78]

Textile recycling activities in Turkey are particularly concentrated in the province of Uşak. Uşak is considered the center of textile recycling in Turkey and undertakes a large portion of recycling activities throughout the country. Recycling facilities operating in Uşak collect old textile products and produce fiber and yarn. These products are used in areas such as socks and home textiles.[79]

6.1. Turkey's Textile Recycling Infrastructure

Turkey's textile recycling infrastructure plays a crucial role in the nation's circular economy, ensuring sustainable waste management and promoting resource efficiency. As one of the world's largest textile producers and exporters, Turkey has been investing in recycling technologies to meet the growing demand for sustainable production. Turkey has established a robust textile recycling industry to address the environmental impacts of textile waste. With the

[75]Zafer Kalkınma Ajansı (2019), Uşak İli Tekstil Geri Dönüşüm Sektör Raporu. Retrievedfrom Kalkinmakutuphanesi:https://www.kalkinmakutuphanesi.gov.tr/assets/upload/dosyalar/usak-tekstil-geri-donusumraporu-tgdr.PDF

[76]Uşak Chamber of Commerce and Industry, TOBB Database (2024)

[77]Ministry of Foreign Affairs. (2021). Defining Circularity of Textile Industry in Turkey.Retrieved fromhttps://www.rvo.nl/sites/default/files/2021/04/Circulair%20Textiles%20Turkey%202021.pdf

[78]Turkey Textile Recycling Market Overview, 2029 (2024). Bonafide Research & Marketing Global Report.

[79]ITKIB Hedef (2024). Türk TekstilveHazırGiyimSektöründe Geri Dönüşüm. 368/Temmuz2024

nation's strong presence in global textile production, a significant amount of waste is generated annually. To counteract this, various collection systems and recycling methods have been implemented. Textile waste is gathered through municipal collection points, retailer take-back programs, and industrial textile waste collection processes. Organizations such as the TEMA Foundation and Ege Tekstil Sanayi contribute to these efforts by raising awareness and managing textile waste.[77]

Sorting and classification are key steps in the recycling process. Turkey employs both manual and automated sorting systems to separate textiles based on material type and usability. AI-powered sorting facilities are emerging to increase efficiency and accuracy.Turkey's textile recycling industry is supported by multiple processing facilities specializing in different recycling methods. Mechanical recycling is one of the most common techniques, where fabrics are shredded and re-spun into fibers to produce recycled yarn. Chemical recycling, which involves breaking down fibers using solvents, is gaining attention due to its potential for recovering blended fabrics. Additionally, upcycling and repurposing methods have been increasingly utilized, transforming used textiles into new products without breaking down their fibers. Major regional distribution hubs for textile waste sorting and redistribution include Istanbul, Gaziantep, and Uşak, with Uşak handling nearly 72% of Turkey's textile waste recycling operations. Uşak, a central hub for textile recycling, is home to multiple large-scale recycling plants. Gaziantep's industrial zone is another key player, focusing on synthetic fiber recycling, while Istanbul and Bursa specialize in high-value recycled textile production. These facilities work to ensure that textile waste is repurposed efficiently, contributing to both environmental and economic sustainability.[76]

The logistics of textile recycling in Turkey rely on a combination of domestic transportation networks, international exports, and digital solutions. Municipal and private sector logistics systems transport textile waste to regional sorting centers before processing. A significant portion of recycled materials is exported to Europe and Asia, where demand for sustainable textile products is high. The integration of digital platforms and e-commerce solutions has improved logistics by connecting waste generators with recyclers, reducing inefficiencies in collection and processing.Despite these advancements, the sector still faces challenges in logistics. High transportation costs, inefficiencies in sorting and storage, and the need for better waste tracking systems remain issues that require solutions. Developing more efficient waste collection networks and investing in tracking technology could significantly improve recycling rates and overall efficiency.

6.2. Turkey'sFuture Outlook and Challenges

Several challenges hinder the full potential of Turkey's textile recycling infrastructure. One of the primary obstacles is low consumer participation in recycling programs. Public awareness regarding textile waste remains low, leading to inadequate collection rates. Furthermore, inconsistencies in municipal waste collection policies create difficulties in establishing standardized recycling practices across different regions.Technological limitations also pose a challenge, particularly in the separation of mixed-fiber textiles. Advanced recycling technologies, such as AI-driven sorting systems and improved chemical recycling processes, are still under development and require substantial investment.

Additionally, some recycling methods consume high amounts of energy, making them less sustainable compared to newer technologies.Economic constraints further impact the sector. The fluctuating prices of recycled fibers make profitability uncertain, while competition with inexpensive virgin textiles discourages manufacturers from investing in recycled materials. Insufficient government incentives for large-scale textile recycling operations also limit industry growth. Implementing policies that provide financial support and subsidies for recycling businesses could help address these economic barriers.

Despite these challenges, Turkey's textile recycling sector presents numerous opportunities for growth and improvement. Innovations in textile recycling technologies, such as AI-powered textile sorting and blockchain-based tracking systems, are expected to enhance the efficiency of recycling operations. Additionally, advancements in chemical recycling could enable the recovery of polyester and blended fabrics, which are currently difficult to process.The expansion of circular economy strategies will play a vital role in the future of Turkey's textile recycling industry. Increased investment in closed-loop textile systems, where fabrics are continually recycled into new textiles, will reduce reliance on virgin raw materials. Collaborations between fashion brands, NGOs, and recycling firms can also foster the development of sustainable products and processes. Moreover, government-backed incentives for sustainable manufacturing could encourage more businesses to participate in textile recycling.

On the international stage, Turkey is well-positioned to strengthen its trade in recycled textiles. The rising demand for sustainable fashion in Europe and North America presents an opportunity for Turkish exporters. Aligning with European Green Deal policies and developing new markets for upcycled textile products could further expand Turkey's role as a key player in global textile recycling.[80]

To improve Turkey's textile recycling infrastructure, several strategic actions must be taken. Strengthening textile waste collection regulations is necessary to increase recycling rates. Providing tax incentives and subsidies for companies using recycled materials would encourage more businesses to invest in sustainability. Expanding public awareness campaigns could educate consumers on the benefits of textile recycling and encourage greater participation.

The industry should also focus on adopting best practices, such as investing in efficient sorting and recycling technologies, establishing dedicated regional recycling centers, and implementing certifications like the Global Recycled Standard (GRS) to improve the credibility of recycled textile products. Businesses should integrate recycled materials into their production lines, while manufacturers should enhance their recycling capabilities through innovation and collaboration with research institutions.

Turkey's textile recycling infrastructure is a key component of the country's sustainability efforts. While challenges persist in collection, sorting, and processing, significant opportunities exist for technological advancements and market expansion. Strengthening recycling logistics, expanding policy support, and investing in advanced recycling technologies will allow Turkey to become a leader in sustainable textile production.The Turkish textile recycling sector is poised for growth, supported by government initiatives, technological advancements, and a global shift towards sustainable practices. However, addressing challenges related to material complexity, quality retention, and infrastructure development will be crucial for realizing the sector's full potential.

[80]European Green Deal Guidelines (2023).Retrievedfrom https://ec.europa.eu/clima/policies/eu-climate-action_en

7. TEXTILE RECYCLING IN UŞAK

Uşak, located in western Turkey, is renowned for its robust industrial base, particularly in textile manufacturing and recycling. The city has a rich history in textile production and has emerged as a significant hub for recycling discarded fabrics into reusable materials. Small and medium-sized enterprises (SMEs) specializing in textile processing drive Uşak's economy, contributing to local employment and promoting sustainable industry practices.

Strategically positioned in western Anatolia, Uşak offers convenient access to major markets in Turkey and Europe. The city spans an area of approximately 5,341 km² and has a population of around 370,000 people.[81] Uşak's economic structure is predominantly based on the textile industry, complemented by food processing, ceramic manufacturing, and leather industries. The city's industrialization has been supported by infrastructure projects such as organized industrial zones (OIZs), which facilitate large-scale manufacturing and trade.

Uşak's industrial sector is characterized by a high degree of specialization in textile recycling. It is home to a number of textile mills and factories that focus on both traditional fabric production and recycling. The industrial zones in Uşak play a vital role in providing a conducive environment for sustainable textile manufacturing. The government, through the Turkish Ministry of Industry and Technology, has incentivized investments in textile recycling, offering tax benefits and grants to companies involved in sustainable production.

In Uşak city; textile, leather, plastic, aluminum and rubber are recycled.

- 740.000 tons of unused industrial textile waste are converted into yarn, fabric, blanket, socks and felt;
- 169.000 tons of sheep and cattle hides are converted into leather garment, accessory industry, furniture, cosmetics, food industry and wool products;
- 117.000 tons of used plastic are converted into fiber and plastic raw materials;
- 12.000 tons of used vehicle tires are converted into tartan track and steel for kids;
- 9.000 tons of scrap aluminum are converted into aluminum powder and foil granules and contributes to the raw material needs of the sectors.

In this way, 2.868 tons of raw materials per day and 1.047.000 tons of raw materials annually are recycled, and zero-value waste and residues that will create environmental pollution for thousands of years are brought back into the economy.[82]

Uşak has become a pioneer in Turkey's textile recycling sector, processing significant amounts of textile waste annually and converting it into new fibers, insulation materials, and industrial cloth. The city is known for hosting numerous recycling facilities that use advanced processing techniques to produce secondary raw materials.Usak textile industry is mainly based on recycling and carries out 72% of the Turkish textile recycling.[83]Companies operating in the recycling sector in Usak employ 25.000 people, of which 15.000 work in the textile recycling sector.[82]

The 2018 Industrial Capacity Report Statistics, published by the Union of Chambers and Commodity Exchanges of Turkey (TOBB) on January 25, 2019, compiles the field of activity and

[81]Turkish Statistical Institute (TUIK). (2023). Annual Industry and Production Data.
[82]Uşak Chamber of Commerce and Industry (2024) Statistical Data, Data Filtered from the Union of Chambers and Commodity Exchanges of Türkiye (TOBB) Database and City Industry.
[83]Union of Chambers and Commodity Exchanges of Türkiye (TOBB)2024 Database.

product codes of workplaces/enterprises according to TOBB records and provides descriptive statistical information by provinces and regions. As is known, capacity reports are documents that show how much production industrial facilities can produce with their machinery parks, personnel structure and the production technology they use. The information contained in capacity reports and compiled within the scope of Industrial Capacity Report Statistics is used to determine the industrial production capacity of the country and to shed light on economic and strategic plans and programs as well as bureaucratic procedures of industrial enterprises. Accordingly, the fields of activity and products that are frequently coded in industrial capacity reports can be considered as indicators of industrial/economic activities concentrated in the relevant province and/or region as well as competitive advantage.[84] According to this data, the most frequently recorded fields of activity and products in Uşak in 2018 are shown in the tables below.

Table 4: The most coded activity in the capacity reports of enterprises in Uşak province(TOBB, 2019)

Order	Code	Description	Number of Capacity Reports
1	13.10	Preparation and spinning of textile fibers	115
2	38.32	Recycling of sorted materials	82
3	15.11	Finishing of textile products	74
4	13.92	Weaving	68
5	13.20	Tanning and dressing of leather; dressing and dyeing of fur	45

Table 5: The most coded product in the capacity reports of businesses in Uşak province (TOBB, 2019)

Order	Code	Description	Number of Capacity Reports
1	13.10.83.40.00	Yarns, blended with cotton, with a synthetic staple fiber content <85% by weight (excluding sewing thread), not put up for retail sale	65
2	38.32.39.00.02	Textile waste recycling	63
3	15.11.41.30.00	Leather (sheep or lamb skins, without wool), tanned, but not further prepared (excluding chamois leather)	43
4	13.92.11.50.00	Blankets and travelling blankets of synthetic fibers (excluding electric blankets)	26
5	13.20.32.20.00	Woven fabrics of synthetic staple fibres, blended solely or predominantly with cotton (with a fibre content of < 85% by weight) (excluding those of yarns of different colours)	24

The textile recycling sector in Uşak comprises various stakeholders, including:

- **Municipal Waste Collection Services**: Facilitating the collection of textile waste from households and commercial enterprises.
- **Private Recycling Firms**: Companies specializing in sorting, cleaning, and reprocessing textile waste.
- **Industrial Textile Producers**: Businesses utilizing recycled materials to produce yarn, fabric, and insulation products.
- **Government and NGOs**: Organizations promoting sustainability through policies and awareness campaigns.

Uşak's textile recycling facilities employ mechanical recycling technique, increasing efficiency and reducing landfill waste.

[84]Zafer Development Agency (2019).Uşak Province Textile Recycling Sector Report.

Post-consumer textile waste, which is considered as household waste in Uşak, is collected by textile waste bins installed in the city. For the establishment of these textile waste bins, collection and organization of the wastes, the Municipality opens a tender and gives this work to companies. The number of textile waste bins in Uşak is 110. There are 2 types of textile waste bins in Uşak. All bins are the same in terms of appearance and sticker design and the area they cover is planned not to exceed 1 square meter. In Uşak, textile waste bins are collected daily by collection teams. An average of 180 tons/year of post-consumer textile waste is collected in Uşak. Post-consumer textile waste collected in Uşak is transported from intermediate warehouses to the Sorting Center in Mersin with daily shipments, where it is subjected to more than 100 classifications. Since there are currently no recycling facilities for post-consumer waste in Turkey, 95% of the waste is exported. The remaining 5% can be sent to facilities in Turkey that recycle wool textile wastes for yarn production.[85]

In the recycling of industrial textile waste, the city of Uşak has a natural cluster that can be an example to the world in the mechanical recycling of post-customer textile waste.In this textile recycling cluster, pre-consumer textile waste (fabric scraps - slaughterhouse wastage) collected from garment slaughterhouses are manually classified and sorted, opened with shredder or garnet machines and turned into fibers, and converted into yarn or nonwoven (felt) products.The open-end spinning method, which is the most suitable method for recycling, is used in yarn production, while the needling method is used in nonwoven surface production.Currently, there are 70 garnet, 60 shredders, 488 open-end spinning machines, 175.000 rotors (in open-end spinning machines), 25 needle-punched nonwoven machines in Uşak.

Recycled textiles from Uşak are distributed to:

- Domestic textile manufacturers.
- Global fashion brands incorporating recycled materials.
- Industrial users for insulation and automotive applications.
- Export markets in Europe and Asia.

Turkey's strategic position as a bridge between Europe and Asia provides Uşak with strong export opportunities, further strengthening its textile recycling industry.

Despite its strengths, Uşak's textile recycling industry faces several challenges:

- **Technology Gaps**: Need for advanced recycling technologies to improve efficiency and quality.
- **Market Volatility:** Fluctuating raw material prices affecting profitability.
- **Regulatory Compliance:** Adapting to international environmental standards and sustainability certifications.

Opportunities for growth include expanding export capabilities, investing in innovative recycling technologies, and strengthening collaborations with global sustainable textile initiatives.

Uşak has established itself as a leader in textile recycling, leveraging its industrial expertise, government support, and international collaborations. Despite challenges, the city's textile recycling supply chain remains robust, offering both environmental and economic benefits. Future advancements in recycling technology and sustainable policies will further enhance Uşak's position in the global circular economy.

[85] Uşak Municipality (2024) Waste Collection Data.

8. COMPARATIVE ANALYSIS OF TEXTILE RECYCLING IN PAIMIOAND UŞAK

Uşak is a city located in western Turkey, known for its strong industrial base, particularly in textile production and recycling. The city has a population of approximately 370,000 and is a key hub for textile waste processing in Turkey. Uşak processes a significant portion of the country's textile waste, transforming it into reusable fibers for various industries.Paimio is a small municipality in southwestern Finland, with a population of about 10,000 people. Unlike Uşak, which is a major industrial hub, Paimio focuses on high-tech and sustainable waste management solutions, including textile recycling as part of Finland's broader circular economy strategy. Table 6 shows the highlights of Uşak and Paimio in terms of textile recycling.

Table 6: Textile recycling in Paimio and Uşak

Paimio	Uşak
Paimio hosts some of Finland's most advanced textile recycling plants, leveraging automation and AI-driven sorting systems.	Uşak accounts for about 72% of Turkey's textile recycling activities.
The city is home to initiatives such as the Rester Oy facility, which transforms textile waste into new raw materials for industries such as construction and automotive manufacturing.	Annually, approximately 740,000 tons of textile waste are processed in the city's recycling facilities.
Finland's government strongly supports sustainable waste management through policies and funding, aiding Paimio's efforts in textile recycling.	The industry provides employment to thousands of workers and contributes to Turkey's economy by reducing dependence on imported raw materials.
Unlike Uşak, where the focus is on large-scale mechanical fiber recycling, Paimio integrates chemical recycling and closed-loop systems to achieve high sustainability standards.	The city's recycling sector benefits from government incentives and private sector investments, supporting technological advancements in fiber regeneration.

The textile recycling infrastructure and technical approach, economic condition of Paimio and Uşak can be compared as follows.

- In Uşak, the focus is on recycling pre-consumer textile waste, while in Paimio the focus is on recycling post-consumer textile waste.
- Uşak relies heavily on mechanical recycling techniques and manual sorting, whereas Paimio incorporates AI and automated systems to enhance efficiency.
- Paimio's recycling methods include chemical processing, enabling higher-quality fiber recovery, while Uşak focuses primarily on mechanical shredding and fiber re-spinning.
- Turkey provides tax incentives and investment support to the textile recycling sector in Uşak, but enforcement of sustainability standards is relatively weaker than in Finland.
- Finland, through its circular economy framework, promotes strict environmental regulations, leading to a more structured and transparent textile recycling sector in Paimio.
- Uşak's textile recycling sector generates significant employment, supporting a large workforce in traditional fiber recovery.

- Paimio, though smaller, contributes to Finland's economy by focusing on innovation-driven recycling methods, with a greater emphasis on automation and high-tech processes.
- Uşak's recycling industry helps mitigate textile waste but is still evolving in terms of energy efficiency and carbon footprint reduction.
- Paimio, with its advanced sustainable practices, has a lower environmental impact per ton of textile waste processed compared to Uşak.

9. CONCLUSION

The textile recycling industry plays a crucial role in sustainable waste management and circular economy initiatives worldwide. This report compares the textile recycling sectors of Uşak, Turkey, and Paimio, Finland, examining their infrastructure, economic impact, environmental policies, and supply chain efficiencies.The comparison of textile recycling in Uşak and Paimio highlights the diverse approaches these cities take to achieve sustainability. Uşak is a leader in large-scale textile waste processing, contributing significantly to Turkey's economy through mechanical recycling and fiber recovery. In contrast, Paimio, while smaller, leads in technological advancements and environmental sustainability through its closed-loop recycling systems and automation.

While Uşak benefits from its extensive industrial infrastructure and workforce, it faces challenges in sustainability practices and regulatory compliance. On the other hand, Paimio, backed by Finland's circular economy policies, focuses on quality-driven recycling with a lower environmental impact.

To enhance textile recycling efforts, Uşak could invest in more advanced sorting technologies and explore chemical recycling to improve sustainability. Paimio, in turn, could expand its recycling capacity and seek partnerships with larger industrial regions like Uşak to strengthen global supply chain integration.

Both Uşak and Paimio play significant roles in textile recycling, albeit with different approaches. Uşak is a leader in large-scale textile waste processing with strong economic contributions, while Paimio stands out for its technological advancements and sustainability-driven policies.

Uşakshouldinvest in advanced sorting technologies and chemical recycling to improve fiber quality and sustainability.Paimio should expand recycling capacity to process a larger volume of textile waste and explore partnerships with larger industrial regions like Uşak for supply chain integration.

By leveraging the strengths of both cities, the global textile recycling industry can move towards a more efficient and sustainable future, balancing economic growth with environmental responsibility.

It is hoped that this report will be a pioneer for the positive cooperation of Uşak and Paimio cities in the future, and will be beneficial for the academia conducting research on textile recycling and the production sector.

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