**Post-consumer textile recycling in the EUROPEAN UNION: policies to increase recycling and status quo of different recycling methods**

BY

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# Abstract

Each year in the European Union, about 5 million tons of clothing are discarded, equating to roughly 12-15 kg per person. Approximately 87% of this waste is classified as post-consumer waste. Despite efforts to address this issue, only around 22% of textile waste is successfully collected for recycling with merely 1% is prepared for the production cycle for new garments. Addressing this issue demands innovative solutions and concerted efforts at both individual and systemic levels to mitigate the environmental impact of clothing waste. Current policy initiatives include the EU Green Deal, the Circular Economy Action Plan, the EU textile strategy, the extended producer responsibility, eco-design requirements for sustainable products, green claims in advertising and business reports, waste shipment regulation, and the European supply chain act – also known as Corporate Sustainability Due Diligence Directive. We present an analysis of the major policies in the European Union for the transition of the textile and apparel industry towards sustainability and highlight initiatives to increase post-consumer textile waste recycling. Furthermore, we provide an overview of innovations and investments in mechanical, chemical and biological recycling in Europe and discuss their potential effects to increase postconsumer textile waste recycling.

**Keywords**: Circular Textiles, Post-Consumer Waste, Recycling Policies, Sustainable Apparel, Textile Recycling.

**Introduction**

Due to its waste, energy consumption and pollution, and its importance to the economy, the textile and apparel industry has been identified in the European Union (EU) as a key industry for transformation within the Green Deal (European Commission, 2024a). As part of this policy initiative the Circular Economy Action Plan was implemented aiming to increase recycling to lower resource extraction (European Commission, 2024b). The objective of the Green Deal and the Circular Economy Action Plan is to significantly reduce waste, environmental pollution and CO2 emissions and at the same time create new jobs and business opportunities to continue economic growth.

Addressing these challenges in the textile and clothing industry requires a multifaceted approach that balances economic growth with environmental and social responsibility, and supports new fibres and chemicals for fabric treatments, as well as recycling. This paper presents an analysis of major policies in the EU and discusses how they may contribute to increase post-consumer textile recycling. Furthermore, it provides an analysis of the state of the art of mechanical, chemical and biological textile recycling in Europe, and discuss their potential to increase pots-consumer waste recycling in-light of the policies.

**Necessity to increase post consumer textile recycling in the EU**

The textile and garment industry holds immense significance for the economic development of numerous countries. The economic success leads to a steep increase in global production of clothing. According to Remy et al. (2016), the global production of garments doubled in the years between 2000 to 2014. This steep growth underscores the industry's rapid expansion and its integral role in economies worldwide. Mass production techniques have evolved to such a degree of efficiency that overproduction has become a distinct possibility. The ability to manufacture vast quantities of clothing at relatively low costs has led to an abundance of goods flooding the market. The affordability of clothing has reached unprecedented levels, enabling overconsumption among consumers. With prices becoming increasingly accessible, people in high and middle income countries in particular are inclined to purchase more garments than they need, contributing to a cycle of excessive consumption and waste. This combination of factors—efficient mass production, overproduction, and overconsumption—poses significant challenges for sustainable practices within the textile and garment industry.

In the EU, the textile and apparel industry is rated fourth in terms of negative environmental impact, after food; housing, and mobility (European Commission, 2023). Each year in the European Union, about 5 million tons of clothing are discarded, equating to roughly 12-15 kg per person. Approximately 87% of this waste is classified as post-consumer waste. Despite recent efforts to address this issue with several policy initiatives, only around 22% of textile waste is successfully collected for recycling. Even more concerning is the fact that so far, only about 1% of the material from discarded clothing is used for the production of new garments (Seele, and Gatti, 2017; <https://environment.ec.europa.eu/publications/textiles-strategy_en>) These numbers are particularly alarming when considering the EU’s expansive membership, comprising 27 member states, and a population of approximately 447 million people with a comparatively high purchasing power, hence, comparatively high clothing consumption. In addition to that is the EU the second largest exporters of the world with 110 Bn EUR including 77 Bn intra EU exports after China with 124 Bn EUR (EEA, 2019), which underlines the economic importance of the clothing sector in the EU.

**Methodology**

In order to identify the EU’s policy initiatives to increase sustainability transition of the textile and apparel sector, we analysed the EU’s communications about the efforts to implement the EU Green Deal (European Commission, 2024a) and the Circular Economy Action Plan which was proposed in 2015 European Commission (2024b). The following policy initiatives have been identified: the EU textile strategy, the extended producer responsibility, eco-design requirements for sustainable products, green claims in advertising and business reports and in the future digital product passport, waste shipment regulation, and the European supply chain act – also known as Corporate Sustainability Due Diligence Directive.

The recycling methods: mechanical, thermo-mechanical, chemical (solvent-based and depolymerisation), and biological recycling hold all different advantages for post-consumer textile waste recycling. We perform a literature and market research based on reports, patents, and industry journals to analyse their state of the art. We discuss, how they are differently effected by the different policies in terms of investments and potential to contribute to the transformation of the textile and apparel sector towards sustainability by increasing postconsumer textile waste recycling.

**Results and discussion**

This section provides an overview and discusses the main policy initiatives and recycling technologies to address postconsumer textile waste recycling.

**Policy Initiatives to Address Post-Consumer Textile Waste Recycling**

EU policy initiatives and legislation aim to mitigate the environmental impact of clothing production and consumption while addressing the question of distributing costs to those who benefit from affordable clothing. The EU Green Deal (European Commission, 2024a) focusses on climate neutrality without compromising economic growth and the promise to “leave no one behind”. The Circular Economy Action Plan European Commission (2024b) provides a framework to reduce resource extraction designing sustainable products, empowering consumers and public procurement, and increase circularity in production processes. While the EU Green Deal and the Circular Economy Action Plan cover guidelines for several industries to achieve climate neutrality by 2050 for the whole EU, the specific actions and measures that are important for the textile and clothing industry are subsumed under the EU Textile Strategy, which is again aligned with the two umbrella initiatives.

**The EU Textile Strategy,** in full: EU Strategy for Sustainable and Circular Textiles (Euratex, 2023), is the leading strategy that includes several actions and implementation measures as well as targets to promote sustainability throughout the textile industry's value chain. It provides a framework for aligning all other initiatives and directives. Table 1 outlines the four key objectives of the EU textile strategy (European Commission, 2024c) and provides and overview of the main policy initiatives and their potential impact on postconsumer textile waste recycling.

**The Ecodesign Requirements for Sustainable Products** (ESPR), proposed in 2022 (European Commission, 2022) after the conditional stakeholder consultation sets standards for product design to improve environmental performance, including requirements related to resource efficiency durability, and reparability. Resource efficiency also includes designing clothing for recyclability and ease of disassembly to increases recycling and therewith reduce resource extraction for clothing. This may also foster more fibre-to-fibre recycling, recovering fibres from textile waste and using these to produce new clothing and textiles products.

**Table 1.** EU Textile Strategy Objectives and Policy Initiatives

|  |  |  |
| --- | --- | --- |
| Objectives | Policy Initiatives supporting the objectives | Effects for post-consumer textile waste recycling |
| 1. All textile products placed on the EU market are durable, repairable and recyclable, to a great extent made of recycled fibres, free of hazardous substances, produced in respect of social rights and the environment2. ”Fast fashion is out of fashion” and consumers benefit longer from high quality affordable textiles3. Profitable re-use and repair services are widely available4. The textiles sector is competitive, resilient and innovative with producers taking responsibility for their products along the value chain with sufficient capacities for recycling and minimal incineration and landfilling | **Ecodesign for Sustainable Products Regulation** including the **digital product passport**, which ensures transparent, traceable, verified consumer and business information (e.g. on material and chemical content, environmental and social aspects)Green Claims Directive and Green Transition Directiveon empowering consumers for the green transition through better protection against unfair practices and better information“Reset the Trend” campaign(#ReFashionNow) informing about business models and approaches for sustainable clothing**Waste Shipment Regulation** may reduce textile waste exportRevision of the **Waste Framework Directive** Ensuring that no textile products are landfilled/ incinerated without ever having been used (e.g. unsold clothes) including **Extended Producer Responsibility** to put responsibility and costs for end-of-life treatment on business who brings it to the market | Designing clothing for ease of disassembly and ease of recycling should increase postconsumer waste recycling, as the waste streams should be easier processed – hence – more affordable in the long-termDigital product passport may inform about fibre-to-fibre recycling and create consumer demand for clothing based on postconsumer textile waste through transparent information Requiring valid information about the environmental and social sustainable performance in combination with the digital product passport may inform consumers and incentivise businesses to use recycled fibres based on post-consumer textile wasteCampaign informing about fashion brands and business models with clothing based on postconsumer textile waste may increase uptakePostconsumer textile waste export restrictions may increase availability for recycling and various recycling marketsStricter waste regulation with extended producer responsibility makes postconsumer textile waste recycling financially more competitive against virgin fibresWaste directive improve regulation on dispatch of clothing and advance collection and sorting systems to channel resource streams for postconsumer textile waste recycling. |

An important feature of the Ecodesign requirements is the digital product passport, which should content information about the environmental impact and social manufacturing conditions of the product to enable consumers to take informed choices and monitoring bodies to carefully observe the fulfilment of sustainability targets (European Commission, 2022). With the digital product passport, the origin of fibres can become known to consumers. Up to now, using recycled fibres in garments is indicated with special hang tags and advertising.

With a digital product passport, it is important to indicate differences of environmental impact of the various recycling methods. E.g., is it more beneficial to use polyester fibres in clothing which are based on plastic bottles, or based on postconsumer textile waste? And how do these polyester fibres compare in terms of environmental impact to biosynthetics, e.g., plant-based polyester made from renewable resources which is also biodegradable, hence has less impact during wearing as fibre shedding is less harmful compared to recycled polyester? Polyester fibres based on recycling will continue to release micro plastic into the environment. However, studies have shown that the type of dyestuff and other auxiliaries have significant impact on biodegradability. Also, the energy sources used for recycling, fibre and clothing production are important. Hence, this will continue to be challenging to establish up to date and correct information for consumers and monitoring agencies, as recycling methods and manufacturing processes continuously improve towards reducing negative environmental impact. To counterbalance potential exaggerations of businesses regarding sustainability claims, the European Commission proposed the following two directives: The **Green Transition Directive** on empowering consumers for the green transition through better protection against unfair practices and better information (European Commission, 2023); and the **Green Claims** **regulations** aim to prevent false and misleading environmental claims in advertising and labelling, ensuring transparency and consumer trust (European Commission, 2022). Both support more accurate information about impact of clothing. However, as e.g. chemical recycling requires a lot of energy and chemicals, this may not compare beneficial to virgin fibres if only the manufacturing and not the overall life cycle impact is analysed. Again, even though these policies could support postconsumer textile waste recycling, it is important to closely monitor which information are included and compared.

To address the objective to increase longevity of clothing and increase the emotional attachment to prolong the use-cycles before dispatch, the European Commission has launched the “Reset the Trend” campaign (#ReFashionNow) in 2023 (European Commission, 2023). With stories featuring fashion labels that make use of recycled clothing, this may increase the fibre-to-fibre recycling market, including recycling of postconsumer textile waste. The campaign also spreads the word about circular business models, which increase intensity and length of product use, and provide repair services. While the campaign targets a rather young audience, it neglects that overconsumption and storage in wardrobes is also a huge phenomenon at middle-aged people, who have a higher income, hence, take purchase decisions more carelessly.

A reform of the **Waste Shipment Regulation** (European Commission, 2024), proposed in 2021 may reduce the export of textile waste and by this increase the availability of postconsumer textiles for EU recycling markets. Waste shipment regulations govern the transboundary movement of waste, preventing illegal dumping and promoting responsible waste management practices. The European Commission claims that the Waste Shipment Regulation “will help restrict the export of textile waste” (European Commission, 2024a). However, it is not clear yet, whether it will reduce textile waste shipment effectively, e.g. by making it more expensive through export taxes or put the burden of proof regarding potential hazardous ingredients to the exporting business. As textile waste is usually non-hazardous, it may not require special treatment.

The **Waste Framework Directive** (WFD) establishes rules for the management of waste, including measures to improve waste prevention, recycling, and recovery (European Commission, 2023). Current waste regulations already prohibit the incineration of unsold garments, though enforcement challenges persist. The proposal to revise the WFD aims to increase second-hand markets to prolong the lifetime of clothing, transforming used clothing, textile products and the fabrics they contain into new clothing (e.g. remaking), as well as recovering fibres from textile waste and using these to produce clothing or other products.

The revision is paired with the concept of the Extended Producer Responsibility initiative (EC, 2018) that requires producers to take responsibility for the environmental impacts of their products throughout their lifecycle, including end of life treatment such as waste collection, and recycling. Traditionally, waste collection and treatment have been municipal services funded through taxes. Extended Producer Responsibility is a concept pioneered by Thomas Lindhqvist in Sweden in the 1990, which shifts the responsibility for waste management costs from taxpayers to producers. Rather than funding waste management through general taxes, the costs for end-of-life solutions are integrated into the product's price, ensuring that only direct consumers bear these expenses. In Germany, the Extended Producer Responsibility has been implemented since 1991 for packaging waste, and at the European level, it is introduced in the Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU) (European Commission, 2023). The Extended Producer Responsibility also entails producers' responsibility to educate consumers on how to correctly dispose of products, promoting better waste management practices. Lessons from plastic recycling indicate that robust institutional frameworks are crucial to combat fraud and ensure the effectiveness of Extended Producer Responsibility schemes. Currently, there are debates amongst stakeholders about appropriate price mark ups for clothing which is difficult to recycle, e.g. due to fibre blends, or have a shorter lifetime, e.g., due to lighter fabric weight and therewith less abrasion resistance. If the Extended Producer Responsibility proofs to be effective and promotes postconsumer textile waste recycling highly depends on the outcome of these discussions.

**The European Supply Chain Act** (or Corporate Sustainability Due Diligence Directive: CS3D; CSDDD) (Maitre-Ekern, E., 2021) proposes requirements for companies to conduct due diligence on their supply chains, including environmental and social impacts, to prevent harm and promote sustainability. The Supply Chain Act could have increased the cost of sourcing garments made from virgin fibres by enforcing businesses to make sure that the whole supply chain is free of social and environmental negative impacts and address the risks appropriately. However, this policy initiative was recently put on hold, amongst others, due to the liberal party of the current German government (European Commission, 2023).

These policy initiatives and directives collectively work to incentivize sustainable practices, hold stakeholders accountable for their environmental footprint, and ultimately reduce the environmental impact of the clothing industry while ensuring fair distribution of associated costs.

**Postconsumer textile recycling technologies**

Recycling technologies are differentiated according to the type of process for recouping the fibers and polymers: mechanical, chemical, and biological recycling. In a more nuanced differentiation, thermo-mechanical recycling forms a subcategory of mechanical textile recycling. Furthermore, chemical recycling can be distinguished into solvent-based polymer recycling and chemical monomer recycling, also referred to as de-polymerization recycling. Biological recycling can be differentiated according to the enzymes, that are used to break up the fibers. The recycling technologies differ in terms of contamination thresholds, but all of them require careful presorting and preparation of the textile waste (Wettengel, J., 2024).

Mechanical recycling is the oldest and most widespread textile recycling technology. Current mechanical recycling comprises physical stress to the fibers because they are cut into small squares and fibers are ripped out of the fabric with teasels and steel brushes, that reduces the fiber length, tensile strength, and abrasion resistance. Hence, for new garments mechanically recycled fibers are usually blended with virgin fibers, usually polyester and sometimes cotton to achieve the necessary properties (Behrendt, T., & Eppinger, E., 2024).

Advantages of this technology include that any fiber blends can be processed. Only high contents of elastane are difficult for the machinery equipment. The process requires low consumption of energy and chemical agents in comparison to other textile recycling technologies. Furthermore, textile waste can be sorted according to colors to reduce chemical processes such as bleaching and re-dying of textiles (Ribul, M., et al., 2021; Ellen MacArthur Foundation, 2017). These advantages make mechanical recycling interesting for post-consumer textile waste recycling.

With the internationalization of the textile and apparel value chain, the number of manufacturing businesses for yarns and fabrics shrunk in Europe. Especially in high-income countries the textile sector focuses on specialized yarns and fabrics for technical textiles. Some non-woven manufacturers who use textile waste exists, however, they prefer industrial waste due to higher consistency of input streams. In combination with increasing availability of low-cost virgin fibers, the number of mechanical textile recycling businesses drastically declined. While the number of businesses focusing on textile waste is slowly increasing again, the businesses lack markets and skilled laborers (Wang, S., & Salmon, S., 2022). As mechanical recycling of textiles is a rather old technology, there is hardly any research funding available, as it is neither innovative nor pre-competitive research. Also industry investments are low compared to chemical recycling.

**Thermo-mechanical recycling** – melting of textiles by applying heat and extruding them into new pallets can be done with thermoplastic fibers such as polyester and polyamide (nylon). On industrial scale, due to the sensitivity to impurities such as haberdashery and dyestuff, and due to the availability of a homogenous waste stream, this is usually done for PET bottles (European Commission, 2022). The few textiles that are used as input for thermo-mechanical recycling are usually pre-consumer waste from clothing production, that do not require extensive pre-treatment and sorting to make it economically feasible (Ellen MacArthur Foundation, 2017; Radhakrishnan, S. et al., 2020; Park, S. H., & Kim, S. H., 2014).

The process does not go without reducing the tenacity of the material. Experience in the industry shows that the tenacity is about 10-20 % lower as compared to virgin polyester fibers. Accordingly, the number of possible recycling cycles in practice is limited and fibers require blends with virgin fibers to obtain suitable properties for application in clothing.

In theory thermo-mechanical recycling holds the advantage to remove thermoplastic fibers from fiber blends, even seem threads and labels that are due to price and durability usually made out of polyester. In practice, this heat treatment would also reduce the quality of the other fibers, even though cotton and cellulosic fibers have a higher heat resistance, the melting temperature of polyester is at 235-260°C, which may damage the other fibers. Accordingly, the recycling method is interesting for recycling of clothing made out of thermoplastic fibers. The potential product applications are non-clothing plastic items, e.g. packaging material with lower tenacity and abrasion requirements than garments.

**Solvent-based (polymer) recycling** is an established process in the textile industry for viscose. Instead of fresh wood as input, also high quality cellulosic fibers such as cotton and linen can be used. But solvents can also dissolve synthetic fibers such as polyester. Hence, fiber blends such as polyester-cotton can be treated with dissolving one fiber material and processing the other material in mechanical recycling streams (Ellen MacArthur Foundation, 2017; Radhakrishnan, S. et al., 2020; Harmsen, P., et al. 2021). The advantages compared to mechanical recycling include potential output of fibers with a tensile strength, abrasion resistance and length of fibers that are comparable to virgin fibers for polyester and to viscose or other cellulosic manmade fibers. Also filaments can be manufactured through this technology. However, the process requires higher energy costs, solvents, and a purer input stream which is only possible for post-consumer waste with careful and – up to date – expensive pre-sorting and pretreatments.

**For chemical monomer recycling**, synthetic fibers are broken up by de-polymerization into oligomers and – depending on the process – into monomers. These resulting substances can be used as input stream for new manmade fibers or other materials. The process allows removing dyestuff and other materials that may impede the quality of the process output. Accordingly, the resulting fibers may have even better properties than fibers from solvent-based recycling (Ribul, M., et al., 2021; Palme, A., et al., 2017). A disadvantage in terms of fiber-to-fiber recycling poses the fact that natural fibers such as cotton cannot be re-polymerized and accordingly processed as open-loop recycling into other glucose-based substances, such as biofuels (Pensupa, N., 2020). Overall, the processing costs and energy consumption is even higher than for solvent-based chemical recycling.

Because of the strong pulp and paper sector, and the strong chemical industry in Europe, there are some larger businesses investing in both, solvent-based and chemical monomer recycling. So far, the fibers are in terms of price not competitive to virgin fibers. However, the processes can combine textile waste and input of new resources, and there are a number of research projects underway, as well as new patent applications and investments in pilot plants in this technology field that document the growing potential to address postconsumer textile waste.

Table 2. Textile Recycling Methods

|  |  |  |
| --- | --- | --- |
| Type of recycling | Benefits | Disadvantages |
| Mechanical recycling | All fibersInexpensive processFiber combinations | Quality (down-cycling) |
| Thermo-mechanical recycling | Established | Only polyester bottles (theoret, possible with nylon) |
| Solvent-based chemical recycling | High qualityChemical contamination can be removed | High energy costSensitive for fiber combinations and contaminationCellulosic and PET fibres |
| Hydrolysis (depolymerization)-based chemical recycling | High qualityChemical contamination can be removed | High energy costSensitive for fiber combinations and contaminationCellulosic and PET fibres |
| Biological recycling | High quality | Each fibre type requires different enzymesSensitive for contaminationOnly lab scale |

**Biological recycling** is the most recent development for textile recycling, utilizing enzymes and microorganisms to break up natural and synthetic fibers into a variety of different materials, e.g. glucose or terephthalic acid (Park, S. H., & Kim, S. H., 2014; Roos, S., 2019). Again, for natural fibers, re-polymerization into new fibers is not possible, but open loop recycling provides a promising option for post-consumer textile waste recycling. Disadvantages include careful sorting and pretreatments that are necessary to remove substances that may impede the recycling process. Depending on the enzymes and microorganisms, the process is even possible at low temperatures, reducing the energy costs significantly. Pre-treatment with chemical agents may reduce the overall processing time and increase the yield (Lee, A., & Liew, M. S., 2021).

The increasing number of research projects, investments in start-ups and patented inventions demonstrate the growing interest in this technology. While this recycling technology is still on lab and pilot scale, due to its benefits it does hold high potential for increasing post-consumer textile waste recycling.

Overall, given the lack of economic infrastructure in the EU as only very few recycling companies, fiber, yarn, fabric and clothing manufacturing businesses are left, the question remains whether it is viable to recycle postconsumer textile waste in Europe and ship the fibers and raw materials to current textile and clothing manufacturing countries, or relocate textile and clothing companies to Europe. So far, there is some funding in the EU mainly for innovative technologies, such as chemical and biological recycling. But overall, there are only few investments, as other sectors such as ICT, mobility, energy, housing, e-commerce and financial services attract much larger investments and corporate finance.

**Conclusion**

Especially mechanical and chemical recycling may increase to tackle postconsumer textile waste in Europe. This however depends to a large degree on how the waste framework directive with the extended producer responsibility will regulate textile waste, to turn it again into a competitive source for new clothing or other products. Moreover, mechanical textile recycling requires a significant labor skill update to speed up postconsumer textile waste recycling.

The ecodesign regulation for ease of disassembly and recycling requires balancing these characteristics with longevity and reparability. The recycling methods are currently improving and their environmental impact depends also on the energy sources which are used for manufacturing. Hence, their environmental impact will improve in the future, which poses a challenge to the information that should be provided in the digital product passport given the long lifetime of garments. As innovative, more sustainable fibres for clothing such as plant-based, biodegradable synthetic fibres with high abrasion strength and tenacity enter the market, this will continue to be challenging to compare their impact to recycled fibres and provide adequate information in the digital product passport for consumers and monitoring agencies to take informed decisions.

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