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Task 4 of the Preparatory Study on textiles for product policy instruments

Ecodesign
EU Green Public Procurement
EU Ecolabel

JRC and AITEX

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Contents

Important!

This document reports only the Task 4 of the preparatory study on textile products. It represents an additional chapter to the 1st milestone, which is available at the following link:

https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2024-02/Textile-Prep-Study_1st-Milestone_20240223.pdf

1 Technologies

This section addresses the Task 4 of the MEErP providing a **general technical analysis of the products in the scope.** This analysis aims to describe the following types of product technologies:

— The Base Case of technologies (BC), which is the average product on the market.

— The Best Available Technologies (BAT), which have the most ambitious performances available on the market. BAT are implemented at scale.

— The Best Not yet Available Technologies (BNAT), which have the most ambitious performances, but they are not implemented at scale, therefore they are considered not available on the market.

In this context, product technologies are products with defined characteristics related to a specific product aspect reported in Article 5(1) of the ESPR, such as durability, repairability, etc.

Section 1.1 identifies the relevant product aspects for the products in scope, and groups those that can be potentially addressed with the same product parameters via future requirements. This approach aims to streamline the multi-criteria analysis that will be performed in the following Tasks of the PS.

Section 1.2 describes the product technologies for each relevant product aspect, analysing the complexity of their ecosystems.

Section 1.3 reports on the influence that product aspects have upon each other and proposes product categories based on the analysis performed in section 1.2. Information reported in Tasks 1 to 4 will feed the models in Tasks 5 and 6, which will describe the base cases and design options, respectively. Each product category reported in section 1.3 will be described with a representative product, which will be used as reference for all products belonging to the specific category.

The analysis performed in section 1 goes beyond the directions reported in the MEErP. It aims to address Task 4 of the MEErP in the context of the ESPR.

1.1 Relevant product aspects

Article 5(1) of ESPR establishes that, in order to address environmental impacts of products, the ecodesign requirements in the delegated acts shall improve a specific list of product aspects. This list includes 16 product aspects:

(a) durability

(b) reliability

(c) reusability

(d) upgradability

(e) repairability,

(f) the possibility of maintenance and refurbishment

(g) the presence of substances of concern

(h) energy use and energy efficiency

(i) water use and water efficiency

(j) resource use and resource efficiency

(k) recycled content

(l) the possibility of remanufacturing

(m) recyclability

(n) the possibility of recovery of materials

(o) environmental impacts, including carbon footprint and environmental footprint

(p) expected generation of waste

Table 15 in section 2.1.1 reports the definitions of these product aspects.

Article 5 of ESPR also establishes that ecodesign requirements in the delegated acts shall be based on the above product aspects, when they are relevant to the product group concerned. Therefore, this section aims to evaluate the relevance of the 16 product aspects in the context of textile apparel. To this aim, two main actions were performed:

- Discarding product aspects that are not relevant in the context of textile apparel;
- Grouping product aspects that can be addressed together in order to streamline the following steps of the study.

Section 1.1.1 describes in general methodology followed, whereas sections 1.1.2, 1.1.3 and 1.1.4 describe the specific steps involved. Finally, section 1.1.5 describes the proposed grouping of product aspects.

1.1.1 Methodology

The analysis undertaken started from the list of 16 product aspects in Article 5 of ESPR, and aimed to: (a) exclude product aspects which were not relevant for textile apparel, and (b) group product aspects that could be potentially addressed with the same product parameters via future requirements. This approach streamlines the multi-criteria analysis that will be performed in the following tasks of the PS.

Non-relevant product aspects were excluded following three steps:

1. Generic description of textile apparel,
2. Guiding questions, and
3. Qualitative assessment.

First, textile apparel were described considering the following characteristics: final vs intermediate product; complex vs non-complex product; and durable vs consumable product. This description set the understanding of the product characteristics that are crucial for steps 2 and 3. Second, key guiding questions identified product aspects that evidently were not relevant for textile apparel. Third, a qualitative assessment investigated technical, socioeconomic and environmental dimensions. This qualitative assessment was based on information found in the literature and did not aim to perform a comprehensive analysis given this will be performed in the following tasks of the PS. The purpose of the qualitative assessment is to further refine the justification to exclude product aspects that are evidently not relevant for textile apparel, and to serve as a basis for the grouping of product aspects.

Finally, only the relevant product aspects were grouped taking into account the characteristics of each product aspect and the product parameters reported in Annex I to ESPR. This grouping streamlined the following steps of the PS because it allowed the use of the same parameters to address more than one product aspect. Therefore, this grouping decreased the number of relevant product aspects to be investigated in the analysis of technologies (see section 1.2) and Tasks 5 and 6 of the PS.

1.1.2 Exclusion of non-relevant product aspects

This section followed the methodology described in section 1.1.1 and identifies product aspects that are considered not relevant for textile apparel.

Generic description of textile apparel

Textile apparel were screened following three sets of characteristics:

- Intermediate product or final product
- Complex product or non-complex product
- Durable product or consumable product

According to Article 2(3) of the ESPR, an intermediate product is a product that requires further manufacturing or transformation such as mixing, coating or assembling to make it suitable for customers. Conversely, a final product is understood to be a product that is already suitable for users. One of the main differences between intermediate and final products is the lifecycle stages that can be considered. While all lifecycles stages could be evaluated in the assessment of final products, in the case of intermediate products a cradle-to-gate approach is followed, where the use stage is disregarded and the end-of-life stage is only partially assessed.

Product aspects that serve to reduce the impacts of use and end-of-life stages would be considered as not relevant for intermediate products. By definition, textile apparel belongs to **final** products, because it is suitable for users.

According to Council Regulation (EC) 6/2002 ([1]), a complex product is a product which is composed of multiple components which can be replaced permitting disassembly and re-assembly of the product. In contrast, non-complex products do not include components or priority parts, thus they do not have components that can be replaced. A product's priority part is functionally important and is likely to fail or to be upgraded. The part will have high priority if it is necessary to deliver either primary (necessary to fulfil the intended use) or secondary functions (necessary to enable, supplement or enhance the primary function) (Cordella, Alfieri, et al., 2019).

Textile apparel belongs to **complex** products, because often it is composed of multiple components which can be replaced permitting disassembly and re-assembly of the product. Additionally, the complexity of textile apparel relies on the numerous fibre types used in blends and processed in several ways along spinning, fabric manufacturing and finishing processes ([2]). Therefore, even textile apparel that is not made of components is considered to be a complex product.

Finally, textile apparel belongs to **durable** products because it is conceived and designed to last. Conversely, once used, consumable products are expected to be consumed or discarded.

Therefore, textile apparel encompasses final, complex and durable products whose relevant product aspects should consider all life-cycle stages, the technological product complexity and its durable function.

Guiding questions

Key guiding questions were used to identify product aspects that evidently are not relevant for textile apparel. These questions addressed only the circularity aspects and did not focus on substances of concern, generic environmental impacts or use and efficiency of water, energy and resources, because these product aspects were considered already relevant based on the analysis performed in section 3.1.3 and 3.3 of the 1st milestone.

Durability

Is the functionality of the textile apparel expected to be provided for a long lifetime and/or for a high amount of multiple uses?

Yes, it is. Therefore, durability can be considered a relevant product aspect.

Reliability

Can the use of the textile apparel or a part/component thereof cause a limiting event in the product?

Yes, fatigue and or ageing of the product (or of a specific part/component) due to its use can cause a limiting event that prevents its use. Therefore, reliability can be considered a relevant product aspect.

Reusability

Could the reuse of textile apparel potentially entail a health risk?

In general, reuse of textile apparel do not entail health risks for consumers. Therefore, reusability can be considered a relevant product aspect.

Upgradability

Would it be technically feasible to upgrade a priority part that could potentially stop functioning, that is already not allowing textile apparel to perform at its fullest and/or there is potential to redesign the product in a way that can be upgraded?

Yes, it is technically feasible to upgrade a priority part in an item of textile apparel. For instance, reassembling a zipper of better quality. It is also possible to redesign textile apparel in a way that they can be upgraded. For instance, improving their ability for disassembly. Therefore, upgradability can be considered a relevant aspect.

Repairability

1 Council Regulation (EC) No 6/2002 of 12 December 2001 on Community designs. Available at this link.
2 A description of this complexity is reported in section 1.2.1.1 and section 2.2 in the Annex.

Would it be technically feasible to repair/replace the no longer functioning priority part and/or there is potential to redesign the product in a way that can be repairable?

Yes, it is. Therefore, repairability can be considered a relevant aspect.

Possibility of maintenance

Will the use and/or storage of textile apparel in specific conditions maintain its expected lifetime or extend it? Would it be possible to postpone a limiting event by performing maintenance activities to any of the parts/components of textile apparel?

Yes, appropriate use and storage of textile apparel can extend their expected lifetime. Moreover, maintenance activities (proper washing, drying and ironing) can postpone limiting events. Therefore, possibility of maintenance can be considered a relevant aspect.

Possibility of refurbishment

Is it technically feasible to refurbish textile apparel by the manufacturer and/or third party operators?

Yes, it is. Therefore, possibility of refurbishment can be considered a relevant aspect.

Recycled content

Is there a waste stream from which material can be recycled and reintroduced in the manufacturing process of textile apparel?

Is the waste stream available for using it in the manufacturing of textile apparel?

Is the waste stream generated within an acceptable distance from the recycling and manufacturing sites?

Can the recycled material be used for the manufacturing of textile apparel with the same or an acceptable minimum quality to keep the properties and function of the product?

Yes, there is a waste stream of textile apparel from which material can be recycled. This material is available for using in the manufacturing of textile apparel. Generally, the waste stream is not generated close to the most common sites for recycling and manufacturing of products. Only post-industrial textile waste is generated at manufacturing facilities. The quality of mechanically recycled fibres is generally lower than that of virgin fibres. Future developments of chemical recycling techniques could produce recycled fibres with the same quality of the virgin fibres. The possibility to incorporate recycled content largely depends on the type of fibre concerned: chemical recycling of cotton waste cannot generate new cotton fibres, but it can generate chemically modified (regenerated) fibres, such as man-made cellulosic fibres (MMCFs). Therefore, recycled content can be considered a relevant aspect.

Possibility of remanufacturing

Would it be technically possible to disassemble textile apparel without damaging those components or parts that could have potential to be used in a new product and/or would be possible to design the product in a way that allows it?

Yes, depending on the specific product and manufacturing process it may be technically possible to disassemble textile apparel so that some parts are used in a new product. It is also possible to redesign textile apparel in a way that they can be remanufactured. Therefore, possibility of remanufacturing can be considered a relevant aspect.

Recyclability

Is textile apparel made of components/parts or materials that can or have potential to be separated and recycled?

Is there available waste derived from the product from which materials can be recovered and recycled?

Is the technology to recycle textile apparel' material available? Is there an existing or potential demand for the recycled material?

Yes, textile apparel is made of materials that can be separated and recycled. There is available waste derived from textile apparel from which materials can be recovered and recycled. Some recycling technologies are already available. There is certain demand for material recycled from textile apparel, although it is limited due to non-competitive prices of recycled fibres. Therefore, recyclability can be considered a relevant aspect.

Possibility of recovery of materials

Besides preparation for re-use and recycling, is there another way to recover materials from the products in the scope?

No, the only way to recover materials from textile apparel is via preparation for re-use and recycling. Therefore, possibility of recovery of materials via any other route can be considered a non-relevant aspect.

The outcome of the qualitative analysis based on key guiding questions is that only the product aspect 'possibility of recovery of materials' can be considered as non-relevant at this point of the analysis.

Qualitative assessment

The qualitative assessment investigated technical, socioeconomic and environmental dimensions of the 15 relevant product aspects screened in in the guiding questions. This qualitative assessment used information gathered through literature review and did not include a comprehensive analysis because this is the aim of the following steps of the PS, mostly the analysis of technologies (section 1.2), Task 5 and Task 6.

The qualitative assessment aimed to further refine the exclusion of product aspects that are evidently not relevant for textile apparel, and to serve as a basis for the grouping of product aspects. In this way, the following steps of the PS can exclude their assessment for a streamlined process.

The qualitative assessment included:

- The technical dimension, which addressed product characteristics and/or improvement potential from a technical perspective.
- The socioeconomic dimension, which addressed the economic feasibility, impacts on job loss/creation and user-related aspects.
- The environmental dimension, which addressed environmental impacts caused by the consumption of the product and potential improvements.

The results of the qualitative assessment showed that all screened product aspects had at least one dimension that resulted relevant for textile apparel. Section 2.1.2 in the Annex provides details of the qualitative assessment.

Finally, **Table 1** reports the outcome of the analysis aiming to exclude non-relevant product aspects.

Table 1. Relevance of product aspects for textile apparel

Relevant product aspects	Non-relevant product aspects
Durability Reliability Reusability Upgradability Repairability Possibility of maintenance and refurbishment Presence of substances of concern Energy use and energy efficiency Water use and water efficiency Resource use and resource efficiency Recycled content Possibility of remanufacturing Recyclability Environmental impacts Expected generation of waste	Possibility of recovery of materials

Source: own production

1.1.3 Grouping of relevant product aspects

Grouping of relevant product aspects aimed to streamline the multi-criteria analysis that will be performed in the following tasks of the PS. Each product aspect represents a criterion of the analysis. If the number of these criteria decreases, the analysis is more efficient.

To this aim, **Table 2** reports some of the characteristics typical for specific product aspects, using the results of the qualitative assessment performed in section 1.1.2. Additionally, **Table 3** reports the direct interaction between product aspects and product parameters reported in Annex I to the ESPR. The product aspects that have common characteristics were grouped because they can be addressed via the same product parameters.

Table 2. Product aspects and required characteristics of products

Product aspect	Required characteristics of products (Annex I of ESPR)
Durability	A highly durable item of textile apparel should have, among others, the following characteristics: high resistance to abrasion, tearing, pilling, colour-fastness, soiling, dimensional changes and seam slippage. It should have easily accessible information for repair and maintenance. Moreover, a durable product should be desirable to the user for a long time. If textile apparel is modular, its priority parts should have easy physical access. Additionally, the process, tools and fasteners required for disassembly should be simple.
Reliability	A highly reliable item of textile apparel should have, among others, the following characteristics: high resistance to abrasion, tearing, pilling, colour-fastness, soiling, dimensional changes and seam slippage. Additionally, a reliable product should be desirable to the user for long time.
Reusability	A highly reusable item of textile apparel should have, among others, the following characteristics: high resistance to abrasion, tearing, pilling, colour-fastness, soiling, dimensional changes and seam slippage. It should have easily accessible information for repair and maintenance. Moreover, a durable product should be desirable to the user for a long time. If textile apparel is modular, its priority parts should have easy physical access. Additionally, the process, tools and fasteners required for disassembly should be simple.
Upgradability	A highly upgradable item of textile apparel should have, among others, the following characteristics: it should be highly modular in design, with easy physical access to priority parts. The process, tools and fasteners required for disassembly should be simple.
Repairability	A highly reparable item of textile apparel should have, among others, the following characteristics: it should be highly modular in design, with easy physical access to priority parts. The process, tools and fasteners required for disassembly should be simple. The product should also have access to repair services.
Possibility of maintenance	An item of textile apparel with possibilities for maintenance should have, among others, the following characteristics: it should have easily accessible information for care in terms of cleaning, drying, ironing and storing the product.
Possibility of refurbishment	An item of textile apparel with possibilities for refurbishing should have, among others, the following characteristics: it should be highly modular in design, with easy physical access to priority parts. The process, tools and fasteners required for disassembly should be simple.
Presence of substances of concern	An item of textile apparel with good information on presence of substances of concern is accompanied with a comprehensive list of all the substances of concern that it contains (above specified thresholds, as appropriate). Substances are used in order to give specific characteristics to the product, facilitate the manufacturing process or to help during the treatment of the product when it becomes waste. Consequently, substances of concern could affect durability, recyclability and environmental impacts.
Energy use and energy efficiency	An item of textile apparel with low energy use or high energy efficiency should (1) be manufactured with low energy consumption, (2) use materials which are not energy intensive in their manufacturing stage, (3) allow to reduce the energy consumption during the use phase in laundering, drying and ironing activities, and (4) be treated at its end of life with non-energy intensive techniques.
Water use and water efficiency	An item of textile apparel with low water use or high water efficiency should (1) be manufactured with low water consumption, (2) use materials which are not water intensive in their manufacturing stage, (3) allow to reduce the water consumption during the use phase in laundering activities, and (4) be treated at its end-of-life with non-water intensive techniques.
Resource use and resource efficiency	An item of textile apparel with low resource use or high resource efficiency should, among other things, use materials that throughout its life cycle stages (1) consume raw materials produced in sustainable way, (2) indirectly use land assuring its future use with the same activity, (3) use ecosystems without damaging their biodiversity and general balance.
Recycled content	An item of textile apparel with recycled content should contain recycled materials, in substitution of virgin materials. The recycled material should come from recyclable textile products to meet the fibre-to-fibre recycling objectives identified by the EU Textile Strategy.
Possibility of remanufacturing	An item of textile apparel with possibilities for remanufacturing should have, among others, the following characteristics: it should be highly modular in design, with easy physical access to priority parts. The process, tools and fasteners required for disassembly should be simple. It should have easily accessible information for repair.

Product aspect	Required characteristics of products (Annex I of ESPR)
Recyclability	In order to be recyclable, an item of textile apparel should meet all the following five characteristics when it becomes waste: (1) it can be effectively collected; (2) it can be sorted, i.e. segregated from other waste and sent to the subsequent recycling pathways; (3) it can be prepared for recycling, or can be sent directly recycling without specific preparation; (4) its fibre content can fully be used as feedstock for one or more recycling techniques to produce recycled fibres usable in textile products; (5) it has no elements or substances that disrupt the collection, sorting, preparation for recycling and recycling, or that limit the use of the recycled fibre.
Environmental impacts	An item of textile apparel with low environmental impact should have, among others, the following characteristics: in all life cycle stages it should (1) use a limited quantity of energy and water, (2) release directly and indirectly a limited quantity of pollutants (e.g. SOx, NOx, COD, microplastics) into the environment, use in the product and emit into the environment minimum possible amounts of substances of concern.
Expected generation of waste	An item of textile apparel with low expected generation of waste should have, among others, the following characteristics: (1) in all life cycle stages, it should generate minimal amounts of waste, (2) it should be designed and manufactured to prevent the generation of post-industrial waste, (3) ideally it should be designed to increase emotional attachment to the user to limit the demand for new products, (4) it should be durable to postpone the demand for new products.

Table 3. Interaction between product aspects and product parameters reported in Annex I to ESPR

Product parameters	Durability	Reliability	Reusability	Upgradability	Repairability	Possibility of maintenance	Possibility of refurbishment	Presence of substances of concern	Energy use and energy efficiency	Water use and water efficiency	Resource use and resource efficiency	Recycled content	Possibility of remanufacturing	Recyclability	Environmental impacts	Expected generation of waste
Product's guaranteed lifetime	■	■	■		■											
Technical lifetime	■	■	■													
Mean time between failures	■	■	■													
Indication of real use information on the product	■	■	■			■										
Resistance to stressor ageing mechanisms	■	■	■													
Characteristics, availability, delivery time and affordability of spare parts	■			■	■		■						■			
Modularity	■			■	■		■						■			
Compatibility with commonly available tools and spare parts	■			■	■		■						■			
Availability of repair instructions	■			■	■		■						■			
Availability maintenance instructions	■					■										
Number of materials and components used	■													■		
Use of standard components	Not applicable to textile apparel															

Product parameters	Durability	Reliability	Reusability	Upgradability	Repairability	Possibility of maintenance	Possibility of refurbishment	Presence of substances of concern	Energy use and energy efficiency	Water use and water efficiency	Resource use and resource efficiency	Recycled content	Possibility of remanufacturing	Recyclability	Environmental impacts	Expected generation of waste
Use of component and material coding standards for the identification of components and materials	■			■	■		■						■	■		
Number and complexity of processes and whether specialised tools are needed	■			■	■		■						■			
Ease of non-destructive disassembly and reassembly	■			■	■		■						■			
Conditions for access to product data	Not applicable to textile apparel															
Conditions for access to or use of hardware and software needed	Not applicable to textile apparel															
Conditions of access to test protocols or not commonly available testing equipment	Not applicable to textile apparel															
Availability of guarantees specific to remanufactured or refurbished products	■			■	■		■						■			
Conditions for access to or use of technologies protected by intellectual property rights	■			■	■		■						■			
Use of easily recyclable materials														■		
Safe, easy and non-destructive access to recyclable components and materials														■		
Material composition and homogeneity														■		
Possibility for high purity sorting														■		
Avoidance of technical solutions detrimental to reuse	■		■													
Avoidance of technical solutions detrimental to upgrading	■			■												
Avoidance of technical solutions detrimental to repair	■				■											

Product parameters	Durability	Reliability	Reusability	Upgradability	Repairability	Possibility of maintenance	Possibility of refurbishment	Presence of substances of concern	Energy use and energy efficiency	Water use and water efficiency	Resource use and resource efficiency	Recycled content	Possibility of remanufacturing	Recyclability	Environmental impacts	Expected generation of waste
Avoidance of technical solutions detrimental to maintenance	■					■										
Avoidance of technical solutions detrimental to refurbishment	■						■									
Avoidance of technical solutions detrimental to remanufacturing	■												■			
Avoidance of technical solutions detrimental to recycling														■		
Use of substances, in particular the use of substances of concern	■							■				■		■	■	
Use or consumption of energy, in one or more life cycle stages of the product	■	■							■						■	
Use or consumption of water, in one or more life cycle stages of the product										■					■	
Use or consumption of other resources, in one or more life cycle stages of the product											■				■	
Use or content of recycled materials and recovery of materials												■				
Use or content of sustainable renewable materials											■				■	
Weight and volume of the product and its packaging											■					■
Incorporation of used components											■					■
Quantity, characteristics and availability of consumables needed for proper use						■										
Environmental footprint of product															■	
Carbon footprint of product															■	
Material footprint of product															■	
Microplastic and nanoplastic release															■	
Emissions to air															■	

Product parameters	Durability	Reliability	Reusability	Upgradability	Repairability	Possibility of maintenance	Possibility of refurbishment	Presence of substances of concern	Energy use and energy efficiency	Water use and water efficiency	Resource use and resource efficiency	Recycled content	Possibility of remanufacturing	Recyclability	Environmental impacts	Expected generation of waste
Emissions to water																
Emissions to soil																
Noise																
Amounts of waste generated																
Functional performance																
Reduction of material consumption																
Load and stress optimisation of structures	Not applicable to textile apparel															
Integration of functions within the material or into a single product component	Not applicable to textile apparel															
Use of lower density or high strength materials and hybrid materials																
Waste reduction																

Coloured cells highlight relevant product parameters for specific product aspects.
Source: JRC own elaboration.

In the context of textile apparel, the product aspects of durability, reliability and reusability were grouped because they have common characteristics and have overlapping aims which can be reached with the same actions. A durable product is likely to be reliable and reusable. **Physical durability** is taken as the leading aspect of this group because it focusses on intrinsic measurable properties of the product which are reported in Annex I to ESPR and allow to indirectly address reliability and reusability. Conversely, emotional durability refers to the emotional attachment that the user has to the product and it does not fall into the definition of "durability" reported in the ESPR (**Table 15** in section 2.1.1 of the Annex). Although emotional durability is not a product aspect, its relevance to the life-cycle environmental impacts of the textile apparel was largely taken into account in the following sections of the PS.

Although the product aspect of **maintenance** is strictly connected to the physical durability, it was addressed separately because it is mostly related to information to be provided to the user, rather than connected to the physical performance of the product.

The third group of product aspects is led by **repairability** which has a definition and characteristics that closely relates to upgradability, possibility of refurbishment, and possibility of remanufacturing. When addressing repairability with product modularity, use of standard components, and the other relevant parameters, the product aspects of upgradability, refurbishment and remanufacturing is indirectly addressed.

The expected **generation of waste** is considered as a product aspect to be addressed individually, providing the feedstock for the recycling system.

The fifth group gathers **recyclability and recycled content**, because recycled material should come from recyclable textile products. From this perspective, these product aspects share the same ecosystem and are affected by the same process techniques, business models, legislation, and industrial practices. More details about this will be provided in the analysis of technologies in section 1.2.5.

The product aspect addressing **environmental impacts** includes the assessment of use (and efficiency) of water, energy and resources, which are the fundamental elements affecting the environment (see section 3.3 of the 1st milestone). The following steps of the PS will develop the environmental and economic model that will take into account all resources used in the entire life-cycle of the textile apparel. In particular, the part of the model related to raw material production will gather available data coming from the most commonly used practices. This approach will support the identification of resource use that less negatively impact the environment in this specific stage. Additionally, Task 5 will report a specific analysis on microplastics release in the whole life-cycle of textile products.

Although the **presence of substances of concern** strongly affects other product aspects, it is suggested to be addressed separately because it mainly refers to information requirements to be reported by the economic operator placing/making available the product on the market. Substances are used to give specific characteristics to the product, facilitate the manufacturing stage, or affects the treatment of the product when it becomes waste. Consequently, substances of concern could directly affect the physical durability, the recyclability, the recycled content and the environmental impacts.

Therefore, the next stages of the PS will address the following groups of relevant product aspects:

- Physical durability, which includes physical durability, reliability and reusability;
- Maintenance;
- Repairability, which includes repairability, upgradability, possibility of refurbishment, and possibility of remanufacturing;
- Generation of waste;
- Recyclability and recycled content;
- Environmental impacts, which include environmental impacts, energy use and energy efficiency, water use and water efficiency, resource use and resource efficiency; and
- Presence of substances of concern.

1.2 Analysis of technologies

For each relevant product aspect, this section describes the product technologies following a four-step analysis:

- Step 1: analysis of the ecosystem related to the specific product aspect;
- Step 2: identification of a methodology to describe the product technologies;
- Step 3: description of the product technologies based on previous steps. This description could be supported by a categorization to best describe the products in the scope.

In step 1, the ecosystem related to the specific product aspect was studied considering four elements:

- the **process techniques**, which are the instruments and practices used along the stages of the product's life-cycle to manufacture or treat product technologies,
- the **business models** of economic operators in the ecosystem,
- the **user behaviour**,
- the **legislative framework** and **industrial best practices**.

In step 2, the methodology used was specific to the product aspect and it was based on the analysis of the specific ecosystem. In step 3, the categorization aimed to gather all products that can be subject to the same future requirements.

Sections 1.2.1, 1.2.2 and 1.2.3 address the extension of product lifespan in term of physical durability, maintenance and repairability, respectively. Section 1.2.4 analyses the waste generation, while section 1.2.5 addresses the recirculation of materials in terms of recyclability and recycled content. Section 1.2.6 analyses the environmental impacts, including the use and efficiency of water and energy. Finally, section 1.2.7 addresses the presence of substances of concern.

1.2.1 Physical durability

This section describes the physical durability of textile apparel, focussing on measurable intrinsic properties linked to the physical resistance against degrading factors due to use and maintenance habits. These degrading factors generate failures, such as fabric breakdown, pilling, loss of dimensional stability and discolouration (Cooper and Claxton, 2022).

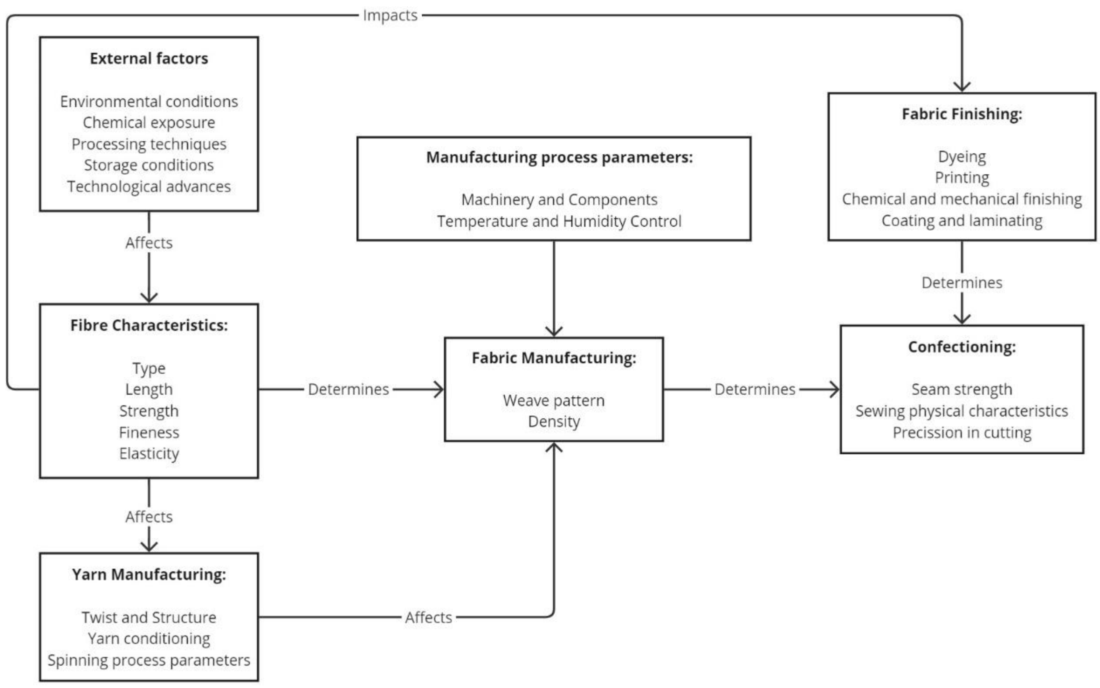
1.2.1.1 The ecosystem of physical durability

Manufacturing factors and process techniques

The characteristics of the product technologies related to physical durability are strictly related to all process techniques involved in the manufacturing stage, as well as the choice of raw materials and the choice of function of the product made at the design stage.

Figure 1 shows a simplification of the complex relations among the numerous factors influencing the physical durability of textile apparel. These factors are grouped according to the specific process during the manufacturing stage. The fibre characteristics directly affect yarn and fabric manufacturing and finishing processes. At the same time, there are external factors such as environmental and storage conditions, and chemical exposure that directly affect the characteristics of the fibres. During the manufacturing of the yarn, the chosen spinning method provides specific levels of evenness, softness and strength. Moreover, spinning parameters such as the twist level, spinning tension, temperature and humidity control play a crucial role on the characteristics of the yarn. The fabric manufacture is strictly related to the final application: weaving is generally used for relatively more rigid and stronger fabrics (e.g. used in pants and shirts), whereas knitting is usually used for relatively more elastic fabrics (e.g. used in T-shirts and dresses). Fabric manufacturing is affected by the specific process techniques used and the ability to control temperature and humidity during the process. During the finishing processes, dyeing and printing give colour-related characteristics, whereas chemical and mechanical finishing provide functional and physical properties, respectively. Fabric manufacturing and finishing directly affect the confectioning process where the physical characteristics of sewing, the precision of cuts and seam strength play an important role in the final appearance and physical durability of the textile apparel. Section 2.1 provides more details about the complexity simplified in **Figure 1**.

Figure 1. Overview of the main factors influencing the physical durability of textile apparel



Source: Own production based on AITEX's knowledge and (Rahman et al., 2023)

User behaviour

Users influence the physical durability of textile apparel mainly at the moment of the purchase when choosing a product with specific characteristics ([3]). Therefore, users set a specific market demand for future products to be placed on the market. This is particularly true whenever the product is placed on the market by a company following the consumer-led operation model (see section 5.5 of the 1st milestone).

The analysis of user behaviour in section 6 of the 1st milestone revealed that product quality is an important parameter taken into consideration when users buy an item of textile apparel. Physical durability is considered one of the main quality aspects. However, when choosing a textile apparel in physical shops, users are driven by their subjective judgement based on the look and touch. When buying online, users still rely on the possibility to check the look and touch of the textile apparel if there is the possibility to return it.

Price is another important aspect that users take into account when buying textile apparel, but they generally do not consider it an indicator of quality, and therefore they also do not consider it to be an indicator of physical durability (section 6 of the 1st milestone). At the same time, the literature revealed that relatively cheap products are disposed of more frequently than higher-priced ones (Morgan and Birtwistle, 2009; Joy et al., 2012). However, no research was found analysing the potential relation between price of products and their intrinsic durability properties.

All in all, although physical durability refers to intrinsic properties of textile apparel, currently users have no way to access this information.

Legislative frameworks and industrial practices

Currently, the industry uses numerous standards to measure specific parameters related to the physical durability of textile apparel (section 4.4 and Table 48 of the 1st milestone). In France, economic operators placing products generating waste on the French market are requested by the Law n° 2020-105 ([4]) to report information about durability of the product. It is unknown to the authors what specific parameters and framework should be used to describe the physical durability of textile apparel in this context.

Business models

Companies in the textile apparel industry adopt numerous business models (sections 5.5. and 5.6 of the 1st milestone). Some of them promote physically durable products and tend to communicate the intrinsic characteristics of the textile apparel. This approach is most common among economic operators dealing with sportswear and workwear. Other companies place on the market textile apparel with high frequency, either to satisfy the demand of customers for new items, or to promote consumption of new collections. Usually, economic operators using this business model would not promote physical durability of the textile apparel because the item would be changed or disposed of by the user relatively soon after purchase.

1.2.1.2 Natural vs synthetic fibres – duality or complexity?

The physical durability of textile apparel is often perceived to be higher for products made with synthetic fibres, compared to those made with natural fibres. This perception may be attributed to the fact that synthetic fibres are man-made fibres designed to be stronger than natural fibres (**Table 16** in section 2.2 reports comparison on characteristics). However, the reality is more complex and the factors influencing the physical durability of textile apparel are multifaceted and interconnected (section 1.2.1.1 and section 2.1). In practice, a textile apparel with a dense cotton fabric and well-constructed seams can outlast a polyester-based product with loosely woven fabric and inadequately constructed seams. Additionally, each fibre and fibre blend has specific properties used for particular applications.

To meet consumer needs, textile apparel must satisfy three key requirements: (1) perform a specific function, (2) meet consumer taste and comfort expectations, and (3) be reasonably priced. Achieving these requirements involves a complex engineering process that takes into account the various factors influencing physical durability. The diverse range of fibres, each with unique characteristics, plays a crucial role in providing specific properties to textile apparel.

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[3] Users also affect the actual lifespan of the products with their maintenance practices, but this topic is addressed in section 1.2.2, where the product aspect of maintenance is analysed.

[4] LOI n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire. Available at this link. Last accessed on 10 October 2024.

As a result, the majority of textile apparel on the EU market is made from blends of natural and chemical fibres (48-60%). Single-fibre products account for a smaller share, with 18-28% made of cotton and 11-17% made of polyester (Refashion, 2023; Bakowska et al., 2025).

1.2.1.3 How to assess physical durability

The assessment of physical durability should evaluate the capability of textile apparel to maintain its properties over time, resisting to aging factors, such as wear and tear and cleaning cycles. The following methodology was adopted in this PS because it takes into account the interaction among manufacturing factors and process technologies (see section 1.2.1.1), the main causes of failures, and the availability of standardised test methods to assess specific parameters.

The methodology comprises five steps:

1. Selection of the key parameters, complying with the principle of economy
2. Identification of the characteristics of a new item,
3. Simulation of the aging process,
4. Assessment of the effects of the aging process,
5. Grouping products with homogeneous characteristics.

The selection of the **key parameters** was based on most common failure modes found in the literature and their corresponding available standardised test methods (**Table 4**).

Table 4. Most common textile apparel failure modes and associated testing parameters

Failure mode group	Type of failure	Occurrence (*) (%)	Associated testing parameters
Fabric related	Pilling	55	Pilling resistance Visual inspection
Colour related	Colour fading	53	Visual inspection
Fabric related	Fabric breakdown	29	Tensile strength Bursting resistance
Fabric related	Accidental damage	29	Determined by the user
Fabric related	Loss of dimensional stability	20	Dimensional stability
Logo failure	Logo failure	16	Visual inspection
Colour related	Discolouration	15	Visual inspection
Fabric related	Hole(s) in seams	14	Tensile strength
Fabric related	Trim failure	8	Visual inspection (without considering the functioning test of buttons and zippers)

(*) Occurrence of failure in the sample analysed by Cooper and Claxton (2022)

Source: (Cooper and Claxton, 2022) and AITEX's knowledge

The identification of the **characteristics of the new item** were fibre-neutral, so that textile apparel made of any type of natural fibres, man-made fibres and their blends could meet the thresholds. This approach took into account the multiple fibre compositions of products in the scope discussed in section 1.2.1.2. The characteristics of the new item were identified based on AITEX's experience in testing textile products.

The **ageing process** of a textile apparel included the effects of numerous factors: the wearing during the actual use, the cleaning (washing or dry cleaning), the drying (line-drying or tumble drying), the potential ironing, and the storage. For the purpose of the methodology, the simulation of ageing only focussed on the simulation of cleaning cycles, because this is the factor that most affects the wear and tear of an item of textile apparel (Neuß and Schlich, 2019; Cooper and Claxton, 2022). In terms of type of cleaning, the literature reports that dry cleaning is mostly used for formal wear, whereas the rest of textile apparel is usually cleaned using washing machines (Laitala and Klepp, 2020). Available standardised test methods are capable to simulate the cycles of washing and dry cleaning (Table 48 of the 1st milestone).

The effect of the ageing process is assessed comparing the performances of an aged product, which underwent a defined number of cleaning cycles, with those of a new product. The difference in performances is expressed as a percentage reporting the decrease of the key parameters. The better-performing products will present a smaller property loss compared to the worse-performing products.

When simulating the aging process, the number of cleaning cycles expresses the objective physical resistance of a textile apparel, which should not be confused with its service lifespan that includes the subjective judgement of the last owner before disposal. The number of cleaning cycles was mainly based on AITEX's experience and validated by their professional network.

The products in the scope are too heterogeneous to be described with the same physical durability parameters and performance levels. Therefore, the scope was divided into **categories** containing all products that can be described with the same key parameters, same performance levels, and undergo the same number of cleaning cycles, because they follow similar manufacturing processes, have similar functions, and count with similar main failure modes. In practice, the technology of the fabric (knitted vs woven) implies specific failure modes, whereas the function implies a defined aging simulation.

The tests for assessing the key parameters were identified taking into account the function of the product and the manufacturing process techniques. This procedure adopted the **principle of economy** based on two aspects:

- The selection of parameters relevant to the specific product category, and
- The optimization of the number of tests, using standardised methods addressing more than one parameter.

For example, the assessment included the performance of the seams when used with woven products and excluded them when seams were used in knitted products. This choice was made because the former are weak parts of the textile apparel, whereas the latter are technically well integrated into the fabric and do not represent a vulnerability of the product. An example about the optimization of the number of tests is given by the assessment of colour fading, discolouration and logo failure via only the standard on visual inspection instead of adding specific colour-related tests.

1.2.1.4 Description of product technologies per category

Table 5 reports the description of eleven product categories from the perspective of the physical durability, whereas **Table 23** reports a description of all standardised test methods proposed in the framework.

Table 5. Product description from the perspective of physical durability

ID	Category description	Key parameter (unit)	Test method	Characteristics of the new product	Simulation of the ageing process
1	Trousers, shorts and skirts, excluding denim	Dimensional change (%)	ISO 3759:2011	±3%	20 washing cycles following ISO 6330 Washing treatment according to label (domestic washing).
		Tensile strength (N)	ISO 13934-1: 2014	Longitudinal: ≥160 N Transversal: ≥120 N	
		Pilling resistance (5-step grading system)	ISO 12945-2: 2020 (2000 cycles)	Grade ≥4	
		Seam resistance (N)	ISO 13935-2:2014	≥100 N	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
2	Denim trousers, shorts and skirts	Dimensional change (%)	ISO 3759:2011	±3%	20 washing cycles following ISO 6330 Washing treatment according to label (domestic washing).
		Tensile strength (N)	ISO 13934-1: 2014	Longitudinal: ≥190 N Transversal: ≥130 N (on seam)	
		Pilling resistance (5-step grading system)	ISO 12945-2: 2020 (2000 cycles)	Grade ≥4	
		Seam resistance (N)	ISO 13935-2:2014	≥120 N	
		Visual inspection for: Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
3	Sweaters, mid-layers and knitted dresses	Dimensional change (%)	ISO 3759:2011	±5%	20 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Bursting resistance (kPa)	ISO 13938-2:2019 (50 cm^2)	≥160 kPa	
		Pilling resistance (5-step grading system)	ISO 12945-1:2020 (14 400 cycles)	Grade ≥4	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
4	T-shirts and polos	Dimensional change	ISO 3759:2011	±5%	30 washing cycles according to ISO 6330 Washing treatment according to label (domestic washing)
		Bursting resistance (kPa)	ISO 13938-2:2019 (50 cm^2)	≥160 kPa	
		Pilling resistance (5-step grading system)	ISO 12945-1:2020 (14 400 cycles)	Grade ≥4	

ID	Category description	Key parameter (unit)	Test method	Characteristics of the new product	Simulation of the ageing process
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
5	Shirts	Dimensional change (%)	ISO 3759:2011	±3%	30 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Abrasion resistance (number of cycles)	ISO 12947-2:2016	≥20 000	
		Pilling resistance (5-step grading system)	ISO 12945-2:2020 (2000 cycles)	Grade ≥4	
		Seam resistance (N)	ISO 13935-2:2014	≥100 N (on confection seam)	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
6	Blouses and woven dresses	Dimensional change (%)	ISO 3759:2011	±3%	20 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Abrasion resistance (number of cycles)	ISO 12947-2:2016	≥15 000	
		Pilling resistance (5-step grading system)	ISO 12945-2:2020 (2000 cycles)	Grade ≥4	
		Seam resistance (N)	ISO 13935-2:2014	≥80 N (on confection seam)	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
7	Jackets and coats	Dimensional change (%)	ISO 3759:2011	±3%	3 cleaning cycles: either following ISO 6330 (washing machine) or following ISO 3175-2 (dry cleaning). For domestic washing, treatment according to label.
		Abrasion resistance (number of cycles)	ISO 12947-2:2016	≥20 000	
		Pilling resistance (5-step grading system)	ISO 12945-1:2020 (2000 cycles)	Grade ≥4	
		Seam resistance (N)	ISO 13935-2:2014	≥100 N (only for blazers)	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	

ID	Category description	Key parameter (unit)	Test method	Characteristics of the new product	Simulation of the ageing process
8	Hosiery: leggings, stockings, tights and socks	Dimensional change (%)	ISO 3759:2011	±3%	30 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Abrasion resistance (number of cycles)	ISO 13770 method 1	≥20 000	
		Bursting resistance (kPa)	ISO 13938-2: 2019 (7.3 cm^2)	≥220 kPa	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
9	Underwear: underpants and boxers	Dimensional change (%)	ISO 3759:2011	±3%	30 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Visual inspection for: (1) Colour change (2) Pilling (3) Trimmings aspect (4) Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
10	Swimwear	Dimensional change (%)	ISO 3759:2011	±3%	15 washing cycles following ISO 6330 Washing treatment according to label (domestic washing)
		Elasticity of fabric (%)	ISO 20932-3:2018	≤7% after 1 minute (only for feminine items)	
		Colour fastness to artificial light (8-step grading system)	ISO 105-B02:2014	Grade ≥5	
		Colour fastness to sea water (5-step grading system)	ISO 105-E02:2013	Grade ≥4	
		Colour fastness to chlorinated water (5-step grading system)	ISO 105-E03:2010	Grade ≥4	
		Visual inspection for: Colour change Pilling Trimmings aspect Self-staining (5-step grading system)	ISO 15487:2018	Colour change: Grade ≥4 Pilling: Grade ≥4 Trimmings aspect: Grade 5 Self-staining: Grade 5	
11	Accessories	NA	NA	NA	NA

The tests addressing dimensional stability and visual inspection need to be run after 1 cleaning cycle.
Washing treatments are supposed to follow information reported on the label. Although this information is usually available, it should not be given for granted because it is not mandatory by law.
All products made with denim fabric should not be tested for colour change because this type of fabric is designed to lose colour over time.
NA: Not available, because the category is too heterogeneous.

Source: AITEX's knowledge

Despite the complexity of the products in scope, two test methods were used to assess five **key parameters** for all product categories: the dimensional change and, via visual inspection, colour change, pilling, appearance of trims and self-staining. All these parameters have to be assessed after a cleaning cycle.

The breakage of fabric took into account the two manufacturing techniques:

- Woven fabrics were described with the tensile strength, seam strength and abrasion resistance;
- Knitted fabrics were described via bursting resistance.

Since pilling is the most common failure mode (see **Table 4**), it was assessed via visual inspection in all categories. Nevertheless, there are specific categories whose function makes these products more prone to rubbing or friction, and therefore a more specific test was included.

Key parameters like elasticity and colour fastness to artificial light, sea water and chlorinated water were chosen to describe swimwear, which have a specific function and are exposed to peculiar external agents like salty and chlorinated water and strong sunlight.

Seam resistance was included in categories with woven textile apparel whose structure and fit design creates stress during movement on the seams, especially in areas like shoulders, sides and armholes. As previously mentioned, knitted products are less prone to seam failure due to the specific interaction between fabric and seams.

The list of key parameters did not include the assessment of trims because:

- Problems with trims are the least occurring failure mode (see **Table 4**);
- The assessment of trim appearance is included in the visual inspection;
- Failures of buttons are the most commonly self-repaired parts of the textile apparel (see section 6.3.3 of the 1st milestone);
- Failure of zippers occurred only 2% of the times (Cooper and Claxton, 2022).

The potential inclusion of specific test methods for buttons ([5]) and zippers ([6]) would clash with the economy principle and would not lead to a substantial improvement in the description of the physical durability of these products.

The values set for the **characteristics of the new products** show that some key parameters decrease their performances even after one cleaning cycle. This is the case of colour change and pilling analysed via visual inspection that can score Grade 4 (slight distortion or damage, minimal and only noticeable upon close inspection), rather than Grade 5 (no visible distortion or damage, fabric maintains its original appearance) after a single cleaning cycle. Additionally, the dimensional change of the fabric can be between 3 and 5%.

Even without undergoing the first cleaning cycle, the new items do not necessarily score at the top of the scale of the tests. This is the case of pilling resistance that can score Grade 4 (slight pilling with some pilling visible but not extensive), rather than Grade 5 (no pilling with no visible pilling on the fabric surface). Additionally, the assessment of colour fastness ([7]) for new swimwear could show similar performances:

- To artificial light: Grade 5 (good light fastness) rather than Grade 8 (outstanding light fastness);
- To sea water and to chlorinated water: Grade 4 (good colour fastness) rather than Grade 5 (excellent colour fastness).

These minimum values assigned to new items underline that new items are sometimes placed on the market exhibiting relatively poor performances as regards the key parameters that describe physical durability.

The reported number of cleaning cycles is aligned with version 2.0 of the PEFCR A&F (Quantis, 2024) and the available scientific literature (Easter and Badgett (2019) and studies reported in section 5.8 of the 1st milestone).

Textile apparel **accessories** were not described because they are too heterogeneous – they would require a further categorization based on their:

[5] Button attachment: UNE EN 17394-2:2021 focuses on children's apparel security.
[6] Zipper attachment and functioning: UNE EN 16732:2016 includes tear tests and zipper fatigue tests.
[7] The colour fastness tests measure how much the colour of the textile apparel fades and stains.

- Function: (1) gloves and mittens, (2) scarves, shawls, and mufflers, (3) ties and cravats, (4) hats and headgear, (5) handkerchiefs and veils, (6) belts and suspenders;
- Material composition: at least (1) silk products vs (2) non-silk products;
- Fabric technologies: (1) knitted, and (2) crocheted.

This would result in **about 16 potential sub-categories**, whose products undergo none or very few cleaning cycles. Consequently, the physical durability should be assessed with specific approaches, which require a disproportionate effort compared to the very small market share of these products. The portion of apparent consumption of accessories compared to the total textile apparel was rather constant from 2006 to 2022. More precisely, the apparent consumption of accessories was about 5% and 4% of the total apparent consumption of textile apparel in terms of mass and value, respectively (Figure 29 in section 9.1.5 of the 1st milestone). Due to this disproportionate effort demand, these products are excluded from the description of the physical durability of textile apparel.

Based on the framework reported in **Table 5**, **technologies of textile apparel** can be distinguished as follows:

- **Bad case** (poorly performing products): performance level of at least one key parameter decreases more than 50% after aging;
- **BC**: performance level of all key parameters decreases between 30% and 50% after aging;
- **BAT**: performance level of all key parameters decreases between 20% and 30% after aging;
- **BNAT**: performance level of all key parameters decreases less than 20% after aging.

The performance decrease of the key parameters should be calculated as reported in **Table 6** and applies to all product categories.

Table 6. Guidance for the calculation of performance decrease in the framework of the physical durability

Result of the test method	Key parameter	Decrease of performance level
Numerical	Abrasion resistance (number of cycles) Bursting resistance (kPa) Dimensional change (%) Elasticity (%) Seam resistance (N) Tensile strength (N)	$\frac{\text{Value after aging} - \text{Value of the new item}}{\text{Value of the new item}} * 100\ (\%)$
5-step grading system	Colour fastness to chlorinated water Colour fastness to sea water Colour change via visual inspection Pilling resistance Pilling via visual inspection Trimmings aspect via visual inspection Self-staining via visual inspection	Each step represents a change of 20%
8-step grading scale	Colour fastness to artificial light	Each step represents a change of 12.5%

Description of all test methods is reported in **Table 23**

Source: own elaboration

1.2.2 Maintenance

Maintenance is the ability of a product to be kept in a condition where it is able to fulfil its intended purpose through one or more actions. In the context of textile apparel, it comprises the set of activities that a user carries out, fundamentally during the use phase, in order to maintain the product in a condition that satisfies their needs. It includes activities such as cleaning, drying, ironing, storing and wearing, in specific environments and conditions. It does not include any operations addressing the repair of the product, which is addressed under a separate specific product aspect (see section 1.2.3).

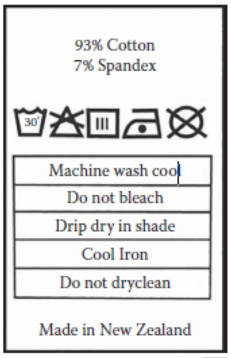
Maintenance operations are specific to the item they refer to. In particular, the fibre composition, the fabric construction type, the presence of non-fibre-based parts and the finishing treatments of the item are crucial factors determining the suitable maintenance strategies to make the product last longer. This section mainly focuses on the information that the manufacturer provides to the user to properly maintain textile apparel.

1.2.2.1 The ecosystem affecting maintenance

Process techniques and design choices

Maintenance instructions are commonly communicated through specific symbols on **care labels**. These symbols are designed to be universally recognisable providing clear guidance on textile apparel care. However, the meaning of some of these symbols is not clear to some users, who tend to mistake the suggested care practices. There are ongoing efforts to standardise and improve the clarity of these symbols by using both **symbols and captions** to facilitate the understanding (Yan et al., 2008; Nayak and Ratnapandian, 2018) (section 9.6.2.7 of the 1st milestone). **Figure 2** shows an example of care label that combines symbols and captions.

Figure 2. Example of a care label combining symbols and caption



Source: Nayak and Ratnapandian (2018)

Traditionally, care labels have been physically sewn during the confectioning phase onto textile apparel, providing essential instructions on washing, drying, and ironing. However, with the rise of digital technology, many brands now complement the physical labels with online care guides and mobile apps. These digital platforms offer more detailed explanations and interactive features that help consumers better understand and follow textile apparel care instructions (Nayak and Ratnapandian, 2018)

User behaviour

Consumer behaviour strongly affects textile apparel maintenance, because the choices made by the users may adhere or not to the best practices reported on the care label. When care information is reported on the item of textile apparel, users could disregard it, have difficulties interpreting the instructions or they could even remove the label because it results uncomfortable when wearing the item (see section 6.3.2 and 9.6.2.7 of the 1st milestone). The removal of physical labels from textile apparel is indirectly promoted by labels displaying a cutting line.

The price of the new item could play an important role when analysing the attention that users pays to care label information. Users are more likely to follow instructions on the care label if they handle a relative expensive product, rather than if they handle a relatively cheap one (Wakes et al., 2020).

Sections 6.3.1 and 9.6.2 of the 1st milestone report the most relevant best use practices in terms or textile apparel care:

- Following information provided in the care label,
- Running laundry with sorted items according to their colour, fabric type, and washing temperature,
- Using the suitable washing temperature,
- Running short washing cycles and reduced spin speed,
- Using the right quantity and type of detergents and softeners,
- Preferring air-drying out of direct sunlight to tumble drying,
- Minimising wash frequency and ironing,

- Properly folding or hanging to prevent fabric deformation
- Storing in cool and dry places.

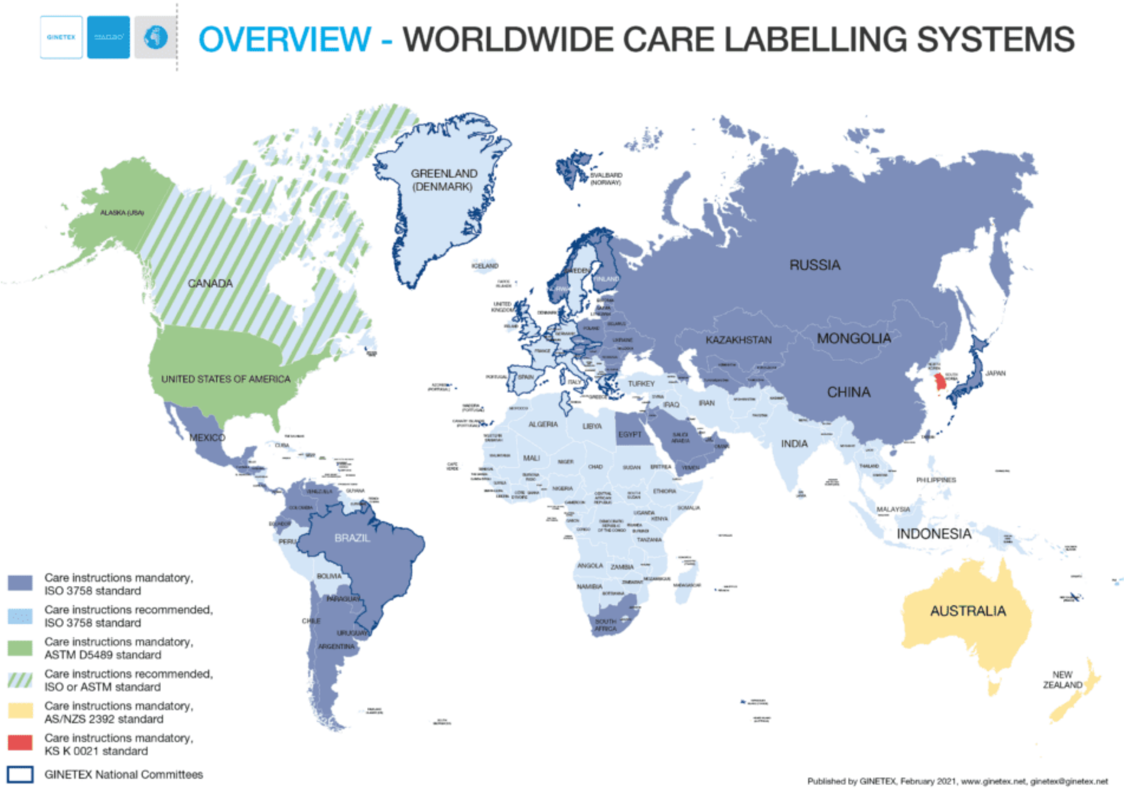
Legislative framework and industrial best practices

Care instructions are not currently mandatory under EU law but they are often provided by manufacturers to prevent customer complaints. Many countries voluntarily follow the GINETEX Standard ([8]), which establishes care labelling system for textiles based on symbols. The European Commission is currently considering the introduction of harmonised and partially mandatory textile labelling rules on textile care, in the context of the review of the Textile Labelling Regulation (EU) 1007/2001 (TLR) ([9]).Nine Member States already require mandatory care labels ([10]) (GINETEX, 2017).

Table 24 in section 2.4 reports the description of standards used in some regions of the world. They mainly differ as regards: (a) temperature units, (b) requirement of captions alongside symbols, (c) adopted symbols, and (4) legal requirements (mandatory vs voluntary).

Figure 3 shows legal requirements and the adoption of standards in specific regions of the world.

Figure 3. Care labelling systems in the world



[8] Ginetex website. Available at this link. Last accessed 12 November 2024

[9] Revision of the Textile Labelling Regulation (EU) 1007/2011. Available at this link. Last accessed on 12 November 2024.

[10] Austria, Bulgaria, Estonia, Finland, Hungary, Lithuania, Romania, Slovakia and Sweden, as well as, in the EEA, Norway.

Source: UK Fashion and Textile Association. Available at this link . Last accessed 12 November 2024. Previously published by GINETEX in February 2021

Table 7 reports the best practices that manufacturers and retailers try to implement.

Table 7. Best practices on care labelling implemented by producers and retailers

Factor	Action
Legibility	Labels should use easily understandable symbols alongside with written instructions. Symbols and letters on labels must remain legible throughout the textile apparel's useful life. The label should use medium-width lettering, where no individual letter should be less than 1.5 mm high.
Parts of the product	If the product is composed of more than one part, the care instruction should take into account the heterogeneity of the product parts.
Comprehensive coverage	Care instruction symbols should apply to the entire textile apparel, including trimmings, zippers, linings, buttons, and sewing thread, unless otherwise specified on separate labels.
Consistent label placement	Labels should be positioned in the same place across all similar items of textile apparel.
Durability of labels	Care labels should be made of materials that are resistant to the care treatments indicated on the label, at least to the same extent as the textile apparel itself.
Material-based instructions	Care instructions should be based on the product's end use and fibre composition. If fabrics contain blended fibres, the care instructions should take into account the most sensitive fibre for the specific treatment.
Pre-sale verification	The care instructions should be verified before being placed on the market to ensure their correctness.

Source: Own production based on (Nayak and Ratnapandian, 2018)

Business models

As previously mentioned, in general companies are interested to provide care instructions to avoid complaints from customers. Nevertheless, this approach could vary according to the business model the company adopts. In general, companies that want to promote long-lasting products might pay particular attention when providing maintenance instructions. Differently, companies that want to promote a fast turnover in the consumption of textile apparel might tend to invest little attention on communicating care instructions.

1.2.2.2 How to assess maintenance

Based on the information gathered in sections 1.2.2.1 and 1.2.2.2, the assessment of maintenance should be based on three main aspects:

1. Type of information provided, addressing all steps of the use-phase:
    - (a) cleaning,
    - (b) drying,
    - (c) ironing,
    - (d) storing,
    - (e) wearing,
    - (f) additional suggestions;
2. Carrier; and
3. Communication strategy.

Information about **cleaning** should address all types of cleaning operations the product can/should undergo: e.g. dry cleaning by professionals or home washing. In the case of professional cleaning, directions should be provided on compatible products for dry cleaning. In the case of home washing, directions should be provided on washing temperature, type and dosing of detergents and softeners ([11]), spin speed, type of textile products that can be washed with it (e.g. similar colours and fibre types).

Information about **drying** should include directions on the optimal type of drying, with specific information regarding drying temperature in the tumble dryer, and sunlight exposure when line drying (air-drying) is used.

[11] In general, specific chemical formulations can weaken certain fibre types increasing the risk of damage (Cooper and Claxton, 2022).

Information about **ironing** should include ironing temperature, and best practices about humidity of the item to be ironed.

Information about **storing** should include directions on how to fold and hang the product, with description of the optimal environmental conditions. If relevant, specific information should be provided distinguishing good practices about storage after wearing from storage after cleaning operations.

Information about **wearing** should specify the function that the product is designed for: e.g. sport activities, leisure time, resistance to humid environment and rain, etc.

Information about **additional suggestions** should include any further information that could support the suitable maintenance of the product.

The **carrier** of information can be a physical label where information is directly reported on it and/or digital-based, where the information can be reached on an online platform. In this case, it should be very clear and simple for the user how to obtain the information.

Finally, regardless of the carrier used, the information should be provided with a **standardised strategy** (or structure), so that users can easily navigate information provided by any economic actor.

This framework is suitable to describe all products included in the scope of the PS without any further grouping or categorization.

Although user behaviour plays a crucial role in the effects generated by product maintenance, the assessment of maintenance in the framework of the ESPR focuses only on the instructions that the manufacturer provides to the user. The behaviour of the user will be taken into account in the environmental and economic models to be built in the following tasks of the PS.

1.2.2.3 Description of products based on maintenance

Table 8 reports the description of product technologies in the context of maintenance of textile apparel.

Table 8. Description of product technologies in the context of maintenance of textile apparel

Information	BC	BAT	BNAT
Cleaning	Using symbols reported in ISO 3758:2023	It reports symbols reported in ISO 3758:2023 explained with captions	It reports all types of cleaning operation the product can/should undergo: e.g. dry cleaning by professionals or home washing. In the case of professional cleaning, directions should be provided on compatible products for dry cleaning. In the case of home washing, directions should be provided on washing temperature, type and dosing of detergents and softeners, spin speed, type of textile products that can be washed with (e.g. similar colours and fibre types).
Drying	Using symbols reported in ISO 3758:2023	It reports symbols reported in ISO 3758:2023 explained with captions	It reports symbols reported in ISO 3758:2023 explained with captions.
Ironing	Using symbols reported in ISO 3758:2023	It reports symbols reported in ISO 3758:2023 explained with captions.	It reports symbols reported in ISO 3758:2023 explained with captions.
Storing	Not available.	Not available.	It includes directions on how to fold and hang the product, with description of the optimal environmental conditions. If relevant, specific information should be provided distinguishing good practices about storage after wearing from storage after cleaning operations.
Wearing	Not available.	Not available.	It specifies the function that the product is designed for: e.g. sport activities, leisure time, resistance to humid environment and rain, etc.
Additional suggestions	Not available.	Reduction of washing frequency and prefer line drying.	It includes any further information that could support the suitable maintenance of the product.

Information	BC	BAT	BNAT
Carrier	Physical label.	Physical label and a website reported on the label.	Physical label is used for basic most important information or warnings, while other information is reachable with a support of a device (e.g. Radio Frequency Identification (RFID) system) incorporated in the product, so that it does not create discomfort and it is difficult to remove.
Communication strategy	Using symbols reported in ISO 3758:2023.	It reports symbols reported in ISO 3758:2023 explained with captions.	Users can easily navigate information provided by any economic actor because it is provided following a standardised format.

Physical labels are usually made of polyester and satin due to their softness and resistance properties (Nayak and Padhye, 2015).
Care symbols use ISO 3758:2023 ([12]).

1.2.3 Repairability

According to the ESPR, the repairability is defined as the ability of a defective product or waste to return to a condition where it fulfils its intended use (**Table 15** in section 2.1.1). In the context of textile apparel, this return to the intended use includes the acceptance by the user, who should still be satisfied with the potential new aesthetics of the product after repair operations. This could be the case for example in the use of patches, mending operations on fabrics, or the use of buttons different from the original ones.

1.2.3.1 The ecosystem affecting the repairability

Design principles for repairable items – choices and process techniques

Textile apparel is often composed by many pieces of fabrics and by non-textile parts such as buttons, zippers and many more. Fabrics could be organised on one or more layers, which could have the same or different fibre composition and properties. Additionally, specific parts of textile apparel could have exclusively an aesthetic function and be made of numerous materials such as leather, plastics, metal and fibre-based. All these parts composing textile apparel are mostly joined with seams, but other ways such as heat-bonding and laser-based techniques are also in use. Furthermore, an item of textile apparel can also be seamless and be made of only one piece of fabric.

The products included in the scope of the PS are very heterogeneous in terms of number, properties and functions of their parts. This heterogeneity goes beyond the intended function of the product, because the same product could be made in numerous ways. For example, a t-shirt can be made of a knitted fabric with no seams, or it can be made by numerous panels of fabric joined with seams, buttons and sequins, resulting in a product made of numerous parts, each of them with a specific function.

Table 4 in section 1.2.1.3 reports that the fabric is the part which is most affected by failures, followed by seams and trims. Fabric is usually damaged by colour fading, discoloration, breakdown, fraying and thinning, pilling and stains.

From the general design perspective, modularity, use of standardised parts and availability of spare parts are believed to be important for product repairability (Cordella, Sanfelix, et al., 2019). **Modular products** are easily disassembled without damaging the product, so that the damaged part can be repaired. In the context of textile apparel, modularity leads to trade-offs with comfort, because seams or components joining different parts of the textile apparel create a discontinuity in the fabric in contact with the skin which is usually perceived in terms of discomfort. Additionally, modularity leads to a trade-off with the physical durability because seams are weak parts of textile apparel.

The **use of standard parts** in the textile industry is rather limited mainly due to its intrinsically creative nature. The European Environment Agency identified fasteners as the main textile apparel part that could be subjected to standardization without affecting the creative nature of this industry (EEA et al., 2022). The size, material and attachment method of zippers, buttons, snaps, and other fasteners could be standardised as well as the thickness of the yarns. However, it is difficult to envisage standardization involving the fabric, which is the main part of textile apparel and which is also the part that is most prone to being damaged (**Table 4** in section 1.2.1.3). The standardization of fabric would potentially limit the creative nature of the textile apparel industry.

[12] ISO 3758:2023 Textiles — Care labelling code using symbols. Available at this link. Last accessed on 13 November 2024.

The **availability of spare parts** in the textile apparel industry should take into account the high number of different collections placed on the market and the real use of these spare parts. Section 5.6 of the 1st milestone report indicated that retailers place on the market up to one collection per week. Making available spare parts for all these different items would imply the manufacture of product parts that most probably would never be used due to the fast changing preferences and attitudes of the users. Additionally, the use of spare pieces of fabric is strictly connected to the fashion trends and user acceptance to wear a product composed by pieces of fabric in a different status (new and worn), which would resemble patches.

Business models

The European Environment Agency estimated that companies working in the textile repair sector decreased in the last decade, reporting that they are small in size and a have a turnover equal to about 0.25% of the apparel textile sales in Europe (EEA et al., 2022). A more detailed analysis of the apparel repair sector is hindered by the way in which collection of this data is performed by Eurostat, which aggregates under the NACE code 95.29 repair of many personal and household goods, including bicycles, books, musical instruments, apparel, etc… ([13]).

In recent years, some fashion brands have started offering repair services to their customers and/or manuals and directions to address some simple repairs of their products, such as replacing a zipper or sewing a button.

Fashion trends depend on many players such as stylists, influencers and fashion brands. They could potentially promote repaired products with for example visible mending and patches, but in reality, such products are not socially accepted in the majority of social gatherings, such as workplaces, parties, etc (Choi et al., 2022; Hong et al., 2024).

User behaviour and economic aspects

The decision of repairing an item of textile apparel is highly subjective and depends on individual values, fashion trends, price, skills and time available to users.

The **emotional attachment** to the product largely influences the decision to repair an item or to replace it with a new one. Textile apparel is more likely to be repaired when it evokes meaningful memories, it is an expression of user identity or provides particular comfort (Page, 2014; Gwilt, 2021; Damhorst, 2019).

The **price of repair** compared to the price of the new item plays a crucial role when the user decides to repair or replace an item of textile apparel. Expensive items tend to be repaired more often than cheap ones due to the cost-effectiveness of the choice (Gwilt, 2021). In particular, if the price of repair exceeds about 40% of the price of the new item, users tend to replace the product rather than repairing it (Cordella, Sanfelix, et al., 2019; Ribeiro et al., 2023). A simple exercise reported in section 2.5 shows that in the EU, professional repair operations can be much more expensive than the purchase of a new item. In this context, the user prefers to buy a new item rather than repairing the damaged one.

When a user decides to repair an item, self-repair is the most common practice followed by unpaid repair via associations such as repair cafes ([14]) and lastly via paid support using professional repairer. Besides economic reasons reported above, it seems that this ranking among different options is largely affected by user mistrust of the capabilities of professional repairers and the cost in terms of time that is associated to repairing operations including logistics (Laitala et al., 2021; EEA et al., 2022; McQueen et al., 2023).

However, self-repair is a viable option only if the user has suitable skills and available time. Usually, users do not have the right skills for self-repair. Although in general women are more likely to repair their defective apparel than men, younger generations, regardless of gender, tend to lack knowledge about the necessary tools, materials and practices (EEA et al., 2022; McQueen et al., 2023; Hernandez et al., 2024). Disregarding user skills, the value given to the time spent in self-repair plays a crucial role when a user decides what to do with their damaged item (Jain, 2021).

Legislative framework and best practices

Currently, there is no legal framework for repair of textile apparel in EU. The promotion of reparability is left to individual fashion brands' voluntary initiatives. However, on 30 July 2024, Directive 2024/1799 on repair of

[13] Eurostat: NACE Rev. 2 – Statistical classification of economic activities in the European Community, available at [this link](). Last accessed 10 October 2024.

[14] Repair cafes are local no-profit workshops where volunteers repair or help repairing numerous goods, including textile apparel. Available at [this link](). Last accessed on 11 November 2024.

goods ([15]) entered into force, with the aim of promoting repair of goods both within and outside the legal guarantee. Member States have to transpose the Directive into national legislation and apply it from 31 July 2026.

Under Directive 2024/1799, manufacturers of products that are subject to reparability requirements under EU law will have to repair those products within a reasonable time and for a reasonable price. For such an obligation to apply, repairability requirements would have to be set in product-specific legislation, potentially for instance in the future Delegated Act on textile products under the ESPR.

Furthermore, manufacturers are required to make information available about their repair services to consumers in an easily accessible manner and consumers will be able to find repairers more easily through a new online European Repair Platform.

Directive 2024/1799 has also amended the existing Sale of goods Directive (EU) 2019/771 ([16]), adding an additional year to the legal guarantee if the choice is made to repair a product instead of replacing it under the legal guarantee.

1.2.3.2 How to assess repairability

Section 1.2.3.1 reported how emotional attachment, fashion trends and repair price strongly affect the success of reparability for textile apparel. In addition to these aspects, repairability can be assessed via more product-related properties identifying the product parts and describing the level of four key parameters: (1) disassembly complexity, (2) tool accessibility, (3) use of standard fasteners, and (4) repair support resources. **Table 9** provides a description of textile apparel in the context of repairability without taking into account potential trade-offs between reparability and physical durability. These trade-offs will be assessed in Task 5 and 6 of the PS.

[15] Directive (EU) 2024/1799 of the European Parliament and of the Council of 13 June 2024 on common rules promoting the repair of goods and amending Regulation (EU) 2017/2394 and Directives (EU) 2019/771 and (EU) 2020/1828 (Text with EEA relevance). Available at this link.

[16] Directive (EU) 2019/771 of the European Parliament and of the Council of 20 May 2019 on certain aspects concerning contracts for the sale of goods. Available at this link.

Table 9. Repairability assessment via four key factors

Key parameters	Relatively easy reparability	Relatively difficult reparability
Disassembly complexity It evaluates how easily parts of textile apparel can be separated without damaging the product.	Product parts can be easily separated without damaging the product. This is especially the case when the product is made of only one part. **Type of connectors:** Temporary seams: Double-stitched or easily accessible seams that can be opened with minimal damage (e.g., simple lockstitch or chainstitch). **Fabric Layers:** Single-layer designs or modular textile apparel (e.g., detachable lining) are easier to access for repair. **Access Points:** Visible and accessible access points: Clear, deliberate access points for modifying or replacing specific parts make disassembly easier.	Product parts are difficult to separate without damaging the product **Type of connectors:** Permanent seams: These are difficult to open without damaging the fabric (e.g., overlocking or serged seams). If the seams must be cut or torn, this lowers the repairability level. Use of adhesives or heat-sealing require specialised tools. **Fabric Layers:** Layered textile apparel: Items with multiple bonded or fused fabric layers are harder to disassemble without damaging the underlying structure. **Access Points:** Concealed or no access points: Products without clear areas to begin disassembly or where components are sealed shut.
Tool accessibility It evaluates whether common household tools can be used to repair the product or if specialised tools are needed. This is strictly connected to the type of product failure.	Common household tools are sufficient for repairs. **Type of Tools Required:** Scissors, needles and thread. **Availability of Tools:** Commonly found in physical or online stores.	Specialised tools are required to disassemble and repair the product. **Type of Tools Required:** Industrial or professional tools like sewing machines and similar tools. **Availability of Tools:** Usually expensive tools available only in professional distribution.
Standard fasteners It evaluates if standard fasteners are used.	Easy to source compatible parts and materials. **Use and availability of standardised fasteners:** It uses standard fasteners that are easily available in physical and online shops.	Difficult to source compatible parts or materials. **Use and availability of standardised fasteners:** Unique/proprietary fastener, which are difficult to source.
Repair support resources It evaluates the availability of repair instructions and services.	Availability of repair support. **Repair instructions:** It includes detailed repair documentation that supports the repair process and it is easily accessible. The guide provides specific instructions tailored to the product via guides, photos, or videos. **Repair services offered:** Accessible in the region where the product is sold.	Absent or very general repair support. **Repair instructions:** It lacks of specific repair information. **Repair services offered:** Not accessible or not available in the region where the product is sold.

Source: own production.

1.2.3.3 Description of products based on repairability characteristics

Following the framework reported in section 1.2.3.2, **Table 10** reports a description of product technologies in the context of repairability. However, the necessary condition for a repairable product is that the price of the repair should be acceptable to the user when compared to the price of a similar new item.

Table 10. Description of product technologies from the repairability perspective

Key parameter	Base Case (BC)	Best Available Technology (BAT)	Best Not yet Available Technology (BNAT)
Disassembly complexity	When products are made of more than one part, their disassembly is highly complex, requiring multiple steps to access damaged parts. The products use standard fasteners, but they are usually hard to access or remove.	When products are made of more than one part, their disassembly has low complexity, with easily accessible parts. The products use standard fasteners, designed for simple removal.	When products are made of more than one part, their disassembly can be performed without tools. The products use fasteners that can be detached and reattached multiple times without damage.
Tools accessibility	The repair operations require basic and specialised tools.	The repair operations require only basic tools.	The repair operations require no tools.
Standard fasteners	Compatible fasteners are available.	Compatible standard fasteners are available.	Compatible standard fasteners are available with personal customization via 3D printers.
Repair support resources	Repair support is very limited, with vague instructions and service limited to portions of the region where the product is sold.	The product has detailed, repair guidance about the failure of most common damaged product parts. Repair services are available in the whole region where the product is sold.	Interactive repair support is available real-time via augmented reality, artificial intelligence or other technologies. Repair services are available in the whole region where the product is sold.

Source: JRC own production.

1.2.4 Waste generation

In this PS, the following definitions were used:

— Textile waste is a textile product which the holder discards or intends or is required to discard ([17]).

— Post-industrial textile waste is textile waste generated during the manufacturing of textile products and their precursors (manufacturing of fibre, yarn and fabric, and during confectioning) (Huygens et al., 2023).

— Pre-consumer textile waste is textile waste generated as a result of discarding unsold textile products.

— Post-consumer textile waste is a textile product that have been discarded after consumption and use by the citizen or end-users of commercial and industrial activities (hotel, care, automotive, etc.). For this reason it is commonly referred to as household and commercial post-consumer textile waste, respectively (Huygens et al., 2023).

Pre-consumer textile waste is generated at manufacturer and retailer stages and it includes the following unsold products:

(a) Finished products that the manufacturers do not send to their customers due to order change or cancellation;

(b) Products that were placed on the market but were not purchased by consumers;

[17] The definition of textile waste is inspired by the definition of waste reported by the Waste Framework Directive (WFD). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance). Available at this link.

(c) Products returned to the retailer after being purchased;

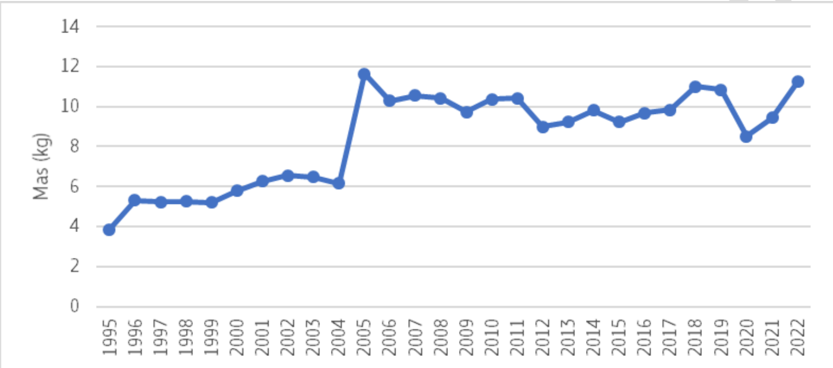
(d) Products that the retailer decides not to place on the market.

This last type of pre-consumer textile waste includes obsolete products belonging to collections that the retailer considers not suitable for the fast changing market, and products that do not meet the retailer' standards, whose remanufacturing is not economically viable (Roberts et al., 2023).

1.2.4.1 Textile waste in numbers

The consumption of textile apparel drives the generation of its waste. **Figure 4** shows that the yearly apparent consumption of an EU-27 citizen increased from about 6 kg before 2005 up to about 10 kg between 2005 and 2022. In particular, in 2019 the EU generated about 6 Mt of textile apparel waste (**Table 11**). A substantial degree of uncertainty exists on these values because Member States and companies have different definitions of textile waste and standards for reporting waste generation, and reporting standards to official databases (e.g. Eurostat) (Huygens et al., 2023).

Figure 4. Apparent consumption of textile apparel per capita in EU-27



Source: own production based on PRODCOM database (Sold production, exports and imports – DS-056120)

Table 11. Amount of textile apparel waste generated due to EU consumption in 2019

Type of waste	Mass (Mt/y)	Contribution to the total (%)
Post-consumer	5.2	87
Pre-consumer	0.16	3
Post-industrial	0.64	11
Total	6	100

Source: Huygens et al. (2023)

Post-industrial waste ranges from 25% to 45% of all fabric used in the production (Aus et al., 2021). The quantity of pre-consumer waste is currently considered underestimated mainly due to lack of transparent reporting (Aus et al., 2021; Duhoux et al., 2024).

In terms of fate of textile waste, it is estimated that about 10% of post-industrial and pre-consumer textile waste is recycled, while the rest is incinerated, landfilled or exported to third countries with unknown final destiny. Only about 5% of the post-consumer textile waste is recycled in the EU, about 17% is exported to third countries and the rest is either incinerated or landfilled (Huygens et al., 2023).

Besides textile waste, the textile industry generates waste from packaging, hangers, which are usually made of plastics, and spent chemicals used in the manufacturing stage. Wastewater is also generated, but it is not included in this analysis because it is addressed in section 1.2.6 on environmental impacts as emissions into water (Roth et al., 2023).

1.2.4.2 Analysis of the ecosystem

Although the types of textile waste have some peculiarities, their generation has some common drivers when focussing on business models and user behaviours.

On one hand, the dominant **business models** of many fashion designers, fashion brands and retailers incentivise the continuous consumption of new products:

— placing on the market up to 47 new collections per year (see section 5.6 in the 1st milestone),

— offering multiple seasonal discounts over the year to incentivise the consumption of products that are considered obsolete, and

— generating a sense of urgency and exclusivity by placing on the market numerous limited editions and using the dark pattern in online sales (see section 6 of the 1st milestone).

In particular, the brand-led operation model promotes new trends via numerous Fashion Weeks and trade shows all around the world, as well as by advertising the proposals of fashion editors, stylists, celebrities and influencers. Additionally, companies using the consumer-led operation model aim to predict the demand of users via trend forecasting agencies or in-house forecasting models, which lead to overproduction to meet the fast changing requests of as many people as possible in different parts of the world (Roberts et al., 2023; McKinsey & Company, 2024; Brondino, 2022).

On the other hand, **users** choose products based on (1) what is available on the market, (2) what is economically convenient, and (3) what makes them feel good and accepted by others. Therefore, the change of user demand depends on the new trends, and the needs of individuals to self-represent and feel accepted when meeting others at work, in their free time and in special occasions (see section 6 in the 1st milestone).

The following three subsections deepen into aspects of the ecosystem that are specific to each type of textile waste.

1.2.4.2.1 Post-industrial waste

When focussing on the manufacturing stages, business models and process techniques largely affect the generation of post-industrial textile waste.

As described in section 5.6 of the 1st milestone, the **business model** of European and North American fashion companies rely on the manufacture of companies located in third countries, which operate as:

— Primary suppliers: main suppliers that provide the products directly to the fashion company.

— Sub-contractors: secondary suppliers that primary suppliers might use to fulfil part of their job.

— Licensed suppliers: companies producing goods under a licensing agreement, which allow them to use in third countries the patents and trademarks of the fashion companies.

Within this structure, suppliers are asked to rapidly produce and adapt to the volatile requests of the market, which could lead to changes or even cancellation of orders. Lead time from the concept of the textile apparel to the potential customer purchase could be as short as 15-21 days. This business model challenges a careful design, resource planning, and quality control during the manufacturing processes. As consequence, post-industrial textile waste increases because (Aus et al., 2021; Zhao and Kim, 2021; Fernandez-Stark et al., 2022; Duhoux et al., 2024; McKinsey & Company, 2024):

- The supply chain is characterised by the bullwhip effect ([18]), where suppliers enlarge their inventories to tackle demand fluctuations;
- Suppliers waste part of their inventories when stock location storage becomes limited;
- Suppliers overproduce to benefit from economies of scale;
- Material belonging to cancelled orders is directly wasted rather than remanufactured;
- Lack of manufacturing quality control leads to low-performing products rejected by fashion brands.

Process techniques adopted in the manufacture of textile apparel are crucial elements conditioning the generation of post-industrial textile waste. In particular, key factors include poor planning, inefficient

[18] The bullwhip effect refers to the phenomenon where order variability increases as the orders move upstream in the supply chain. The bullwhip effect is sometimes referred to as 'demand amplification', 'variance amplification' or the 'Forrester effect'. This effect becomes significant when the cost from fluctuations in production/ordering outweighs the cost of holding inventory (Wang and Disney, 2016).

manufacturing systems and cutting methods, as well as suboptimal fabric utilisation (Aus et al., 2021; Khairul Akter et al., 2022).

At the confectioning stage, cutting operations are the largest contributors of this type of waste, followed by mistakes during sewing and damages to fabrics (Aus et al., 2021; El Shishtawy et al., 2022; Vilumsone-Nemes et al., 2023). On one hand, design software like CAD (Computer-Aided Design) and the use of artificial intelligence can optimise the use of fabric and decrease the generation of post-industrial waste by 27% when compared to manual cutting (Krsteva and Demboski, 2011; Palacios-Mateo et al., 2021). On the other hand, sewing operations are semi-manual activities affected by the performance of the machinery and the pressure put on the operators to meet the tight deadlines of rapid production (Aus et al., 2021).

In general, the manufacturing process could be optimised adopting methodologies such as Lean Manufacturing, Total Quality Management, Kaizen, Just-In-Time (JIT) and Lean Six Sigma. The adoption of these methodologies optimise processes, improves the alignment of demand and production and reduces the incidence of defective goods (Saleeshya et al., 2012; Harpa et al., 2024).

However, despite technological developments, there is lack of standardised industrial best practices that enable the reduction of post-industrial textile waste. The authors are not aware of any specific **legislation** in producing countries specifically addressing this type of textile waste.

1.2.4.2.2 Pre-consumer waste

When focussing on the retailer stage, all elements of the waste generation ecosystem play an important role.

Process techniques related to the efficiency of the reverse logistic could decrease the number of destroyed returned products avoiding that more items get lost, damaged or with time become obsolete. The literature reports different improvement potential when adopting the Best Management Practices: pre-consumer waste due to returns could be decreased from 44% to 22% or from 25% to 13%. Moreover, detailed product descriptions, especially on size and fitting, could support informed purchase and therefore reduce the number of returns (Ahlström et al., 2020; Duhoux et al., 2024; Roichman et al., 2024).

The **business model** concerning return policies of the retailer and the marketplace plays a relevant role. To overcome reverse logistic issues, some fashion brands offer an integrated shopping experience that combines e-commerce and physical stores. In this case, customers can purchase online and potentially return in physical stores where they can get customised recommendations (McKinsey & Company, 2024).

The bullwhip effect characterising the manufacturing processes affects invest also retailers, who try to enlarge their inventories to meet the requests of the changing market (Fernandez-Stark et al., 2022; Duhoux et al., 2024; McKinsey & Company, 2024). As a consequence, as soon as fashion trends change, new collections generate obsolete goods that remain unsold. Therefore, items less affected by changing trends and with high demand are less likely to remain unsold (Duhoux et al., 2024).

Section 6.4.4 of the 1st milestone reported that **users** are not aware of the consequences of returning items of textile apparel after their online purchase – most of them think that the items are always re-sold. The investigation showed that customers find convenient purchasing online when returns are free of charge. In these cases, customers have the opportunity to try and touch the product directly at home without going to the physical store. This opportunity sometimes evolves to the extreme behaviours of bracketing and 'wardrobing'. The former describes users purchasing multiple sizes of the same item and returning those that do not fit. The latter describes consumers purchasing expensive items, wearing them, and then returning them (see section 9.6.3 of the 1st milestone).

From a **legislative perspective**, the destruction of pre-consumer textile waste is often preferred by companies because there are taxation advantages related to VAT payment (Duhoux et al., 2024). With the entrance into force of the ESPR, from 19 July 2026, the destruction of unsold textile products is prohibited unless derogations apply in cases where destruction is necessary, for instance due to health and safety reasons. Only micro and small enterprises will be exempted from this prohibition. However, the ESPR addresses only the unsold products that are placed on the EU market, while it does not address pre-consumer textile waste generated at manufacturing stage.

1.2.4.2.3 Post-consumer waste

When focussing on the end-of-life of textile apparel, the analysis of reasons for textile apparel disposal sheds light on what mostly affects the generation of post-consumer waste. The investigation reported in section 6.2.1 of the 1st milestone highlighted three main reasons:

1. The loss over time of product intrinsic performance,
2. The change in perceived value, and
3. The change over time of the body shape of the user resulting in unfitted textile apparel.

The first reason is strictly connected to the physical durability of the product over aging processes. The second reason is related to the desire or need to change the textile apparel due to changing fashion trends, personal tastes, or social life. The third reason is connected to physiological change of the human body over time.

In addition to these three factors, a study revealed that users are more prone to dispose of cheaper products than of higher-priced items because they usually develop higher emotional attachment to the latter than to the former (Forbrugerrådet Tænk, 2022).

From the **legislative perspective**, the Waste Framework Directive (2008/98/EC) and the recently published revision of the Waste Shipment Regulation (2024/1157) (WSR) ([19]) regulate the management of post-consumer waste in EU and its potential shipment within the EU and from the EU to third countries, respectively. In particular, the proposal to establish Extended Producer Responsibility (EPR) schemes for textiles in all EU Member States should ensure that producers will cover the costs of textile waste management and research and development on e.g. recycling technologies (see section 4.1.2 of the 1st milestone). Additionally, the WSR allows the shipment of textile waste produced in EU only to non-OECD countries that have expressed their willingness to receive the waste and demonstrate the ability to treat it in an environmentally sound manner ([20]).

1.2.4.3 How to assess and describe product technologies in the context of waste generation

The generation of waste is not an intrinsic property of a single product technology, but rather depends on many elements of its ecosystem, and is driven by the total consumption of textile apparel. Currently, it is not possible to understand if a product was manufactured using specific process techniques and under particular business models. Moreover, it is unknown how many companies use advanced technologies to minimise their post-industrial and pre-consumer waste. Nevertheless, the study of the literature and the consultation with stakeholders reveals that the majority of the products consumed in EU are produced with the business models incentivising overconsumption and overproduction as described in section 1.2.4.2.

To sum up, it is difficult to distinguish BC, BAT and BNAT among the product technologies placed on the market. In the following steps of the preparatory study, the description of waste generation will be modelled taking into account the variability and uncertainties of all factors playing a role: the influence of the dominant business models, user behaviours and the general performances of available process techniques.

1.2.5 Recyclability and recycled content

This section analyses the recyclability and recycled content of textile apparel starting from their definitions reported in section 1.1:

- **Recyclability** is the ability of products after becoming waste to be reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.
- According to the ISO 14021, the **recycled content** is the proportion, by mass, of recycled material, from pre- and post-consumer waste, in a product or packaging.

These definitions will be revised in the end of this section based on the analysis of this specific product aspect.

[19] Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006. Available at this link.

[20] Decision of the Council on the Control of Transboundary Movements of Wastes Destined for Recovery Operations. Available at this link. Last accessed on 18 October 2024.
The Waste Shipment Regulation (2024/1157) prohibits the exports of textile waste (Basel Convention entry B3030) destined for recovery in countries to which the OECD Decision does not apply. Specific countries can be included via a Delegated Act (see Article 41).

1.2.5.1 The ecosystem of recyclability and recycled content

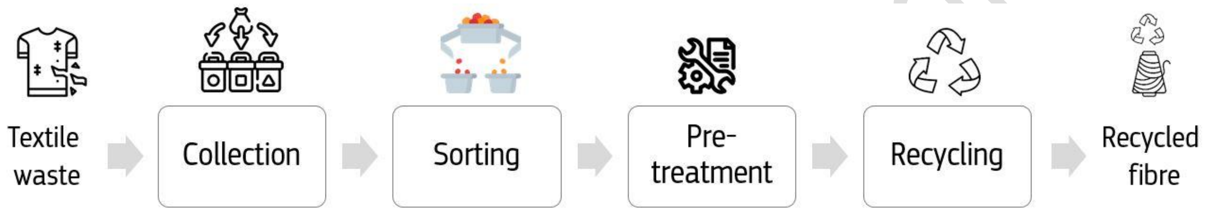
Process techniques and design choices

Figure 5 shows the description of the recycling system of textile waste aiming to produce recycled fibres.

In the first place, textile waste is collected separately from other waste fractions and is subsequently sorted following criteria that depend on the techniques used in the following stages of the recycling system. Then the waste is treated to prepare the material for the following process and finally it undergoes the actual recycling process that results in a recycled fibres output. The recycling process includes recycling techniques and potential further treatments to obtain the recycled fibre ([21]). **Figure 5** does not include the transportation of the waste potentially occurring between different processes because it is not relevant to the analysis performed.

In this section, only the waste undergoing recycling will be described but the reader should keep in mind that the waste management of textile waste includes all processed described in section 9.2.8 of the 1st milestone.

Figure 5. Recycling system of textile waste



Source: own elaboration using icons from www.flaticon.com

The separate **collection** of textile waste guarantees that this waste fraction can enter the recycling system.

Since post-industrial textile waste is managed by manufacturers, the waste is already separated from other waste fractions and it is directly delivered to other actors of the value chain. When the waste is generated at fibre stage, the spinnable part is usually reintegrated in the manufacturing process, whereas the non-spinnable part is usually given to other actors of the value chain for further applications, such as nonwovens filters, insulation, and filling (Boschmeier et al., 2024). When the waste is generated during spinning, broken ends of slivers and laps are usually reintegrated in the manufacturing process, whereas waste from blow-room machines and carding is usually given to other actors of the value chain for further treatments or applications (Bedez Ute et al., 2019). Differently, when the waste is generated during the manufacturing of fabric or confectioning, manufacturers may send the waste to specialised companies for further treatments or disposal.

Similarly to the post-industrial textile waste, the pre-consumer textile waste is managed by manufacturers and retailers. Also in this case, the waste is already separated from other waste fractions and it is directly delivered to other actors of the value chain.

The separate collection of post-consumer textile waste includes pick-up and drop-off schemes. Pick-up schemes involve scheduled collection routes targeting specific waste types, such as bulky or frequently disposed waste. In pick-up schemes, consumers are usually provided with containers, especially in door-to-door or kerbside collection. Alternatively, drop-off schemes require individuals to deliver their waste either to designated containers or through take-back systems offered by retailers. In Europe, post-consumer textiles waste are mainly collected via drop-off containers (Huygens et al., 2023).

In the recycling system, **sorting** is relevant mainly for post-consumer waste. Post-industrial waste and pre-consumer waste do not need to be sorted because at the generation site, manufacturers and retailers, the waste is already segregated according to similar characteristics, such as cut-offs of the same fabric, or the unsold items belonging to the same collection. However, returned items could be an exception – according to the retailer logistics, this waste could need to be sorted.

[21] This happens because the output of recycling techniques can be an intermediate product that needs to be further treated before becoming a recycled fibre. **Table 12** provides more details.

At sorting facilities, items are sorted according to their reusability, composition and colour. The sorting criteria are set by second-hand traders and recyclers looking for items with specific characteristics. There are mainly three types of sorting techniques (EuRIC, 2021):

- Manual sorting relies on human inspection of the waste. It is particularly accurate, especially when sorting reusable items, but it is labour-intensive and takes a relative long time.
- Automated sorting uses machines equipped with near-infrared (NIR) spectroscopy to identify the colour and the surface composition of the items. It is fast, but it not as accurate as human inspection.
- Hybrid sorting combines human inspection with automation to balance accuracy and efficiency.

The sorting process is mainly challenged by the difficulty to accurately identify the fibre composition of the textile waste. On one hand, the reading of the fibre composition reported on labels is time consuming if done with human inspection. Information is not necessarily accurate or it could be even not accessible due to absence of the label or removal of the writing due to ageing processes. On the other hand, the use of near-infrared spectroscopy has difficulties when used for multi-layered items, or on items with layered fabrics, whose outer fibres are different from the inner ones.

After sorting, the waste undergoes **pre-treatment**, which optimises the material processing in the specific recycling technique to be used. Usually, during pre-treatment, non-textile parts are separated from the parts containing fibres. This is commonly done manually, with loss of some part of the fabric, while new process techniques use mechanical separation together with shredding of the waste. Alternatively, other new process techniques allow disassembly of waste in cases where specific stitches have been used for the confectioning. These stiches can be loosened or dissolved under specific electromagnetic or heat treatments, respectively. During pre-treatment, fabrics are usually shredded to improve the efficiency of recycling technology adopted in the following step of the recycling system.

Table 12 reports the status of the **recycling techniques** in 2023. Available techniques were described via their feedstock, the main recycling output, the possibility to deal with disruptors and their maturity. Each technique can process feedstock with specific characteristics and can provide recycled fibres with specificities that affect their application in textile products. Additionally, disruptors like non-textile parts, dyes, coatings, and undesired fibres (e.g. elastane) could be an obstacle for some techniques, but not for all of them. The level of maturity of the techniques refers to 2023, but the general picture could rapidly change given the fast technical evolution of the sector.

Table 12. Status of recycling techniques for textile waste in 2023

Recycling technique	Feedstock	Main output	Disruptors	Maturity of the technique and comments
Mechanical recycling	Textile waste almost exclusively constituted of cotton, wool, or synthetic fibres. Blends are usually not processed.	Recycled fibres are shorter than virgin fibres.	Non-textile materials have to be removed. Fibre contaminants and colours of feedstock will be transferred to recycled fibres. This usually requires colour sorting before recycling.	It is the most commonly used technology at scale. Recycled fibres have lower mechanical properties than virgin fibres. This usually forces the use of recycled fibres with virgin fibres. The mechanical characteristics of the recycled fibre limit its application. A portion of recycled fibre is usually not spinnable. The physical and mechanical characteristics of the recycled fibres highly depend of the status of fibres used as feedstock.
Thermo-mechanical recycling	Textile waste constituted of fibres based on thermoplastic polymers. High purity is required. Input textile waste should consists only of one polymer type (e.g. acrylic, nylon, polyester) or of compatible polymer types.	Polymers in the form of granulate or fibres	Non-textile materials have to be removed. Pigments and dyes remain in the output material.	It is at about TRL=7. During the process the polymers/fibres are deteriorated. Thus, recycled fibres should be blended with virgin fibres.
Chemical recycling for cellulosic fibres	Textile waste mainly constituted of cellulosic fibres. Presence of impurities and non-targeted fibres decreases the efficiency of the process. A specific process step removes impurities and non-targeted fibres.	Regenerated cellulose as pulp.	Non-textile materials are removed before or during the process. A process stage removes dyes and finishes. It has a bleaching step similar to the traditional wood pulp production.	Most technologies have reached high readiness (TRL=7-9). This is particularly true for feedstock with pure cotton. The potential degradation in length and strength of the cellulosic fibres influences the performance of the regenerated pulp.
Chemical recycling for synthetic fibres (mainly PES and PA6)	Textile waste constituted of at least 80-90% PES or PA6.	PES or PE6 monomers/oligomers.	Non-textile materials are removed before or during the process. Contaminants like dyes can be handled to achieve homogeneous colours of recycled monomers/oligomers.	Depolymerisation techniques processing PA6 are operational at scale. Techniques processing PES have TRL=4-7 and are expected to enter the market within less than 5 years.

Recycling technique	Feedstock	Main output	Disruptors	Maturity of the technique and comments
Chemical recycling for wool-rich blends or polycotton fabrics	Textile waste rich in wool, or textile waste made of polycotton. A degree of contamination is accepted by specific techniques.	Depending on the process, the output is: - wool fibres ready for carding; - cellulosic pulp; - PES fibres, polymers, or monomers.	Non-textile materials are removed before or during the process. Colours can be removed also via bleaching.	Wool recycling using hydrochloric acid is at operational scale. The solvent-based dissolution and filtration technique used for polycotton is currently at TRL=5-6. The hydrothermal techniques used for polycotton are at TRL=6-7. The enzymatic technique used for polycotton is estimated to be at TRL=5.
Thermo-chemical recycling via pyrolysis and gasification	Textile waste with any fibre composition.	Syngas or pyrolysis oil, which could serve as a basis to produce methanol and then transform the methanol in different monomers for later polymer production.	Non-textile materials are removed before or during the process.	Pyrolysis has already been implemented as industrial scale (TRL 9), but applications for textile waste treatment are unknown. Syngas and pyrolysis oil are usually used as fuels.

TRL: Technology Readiness Level, which is a 9-grade scale. TRL=1: Basic principles observed; TRL=2: Technology concept formulated; TRL=3: Experimental proof of concept; TRL=4: Technology validated in lab; TRL=5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technics); TRL=6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling techniques); TRL=7: System prototype demonstration in operational environment; TRL=8: System complete and qualified; TRL=9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).

PES: polyester; PA6: polyamide/nylon 6; Polycotton: blend made of cotton and polyester

Source: own elaboration based on (Duhoux et al., 2021; Lu et al., 2023; Huygens et al., 2023) and inputs from stakeholders.

Overall, the most used recycling technique is mechanical recycling which processes mono-fibre textiles, preferably cotton and wool. Blends are not usually processed with mechanical recycling because the output would be a mix of fibres with different properties that have very difficult application in textile products. This happens because the characteristics of the feedstock are directly transferred to the recycled fibres, which in addition have lower mechanical properties than fibres in the feedstock. These characteristics of the mechanically recycled fibres largely limit their applications and force to spin recycled fibres with virgin high-performing fibres (**Table 12**).

Chemical recycling of man-made cellulosic fibres is also implemented at operational scale, especially when feedstock is made of pure cotton, even though process capacities in the EU are still low. Also regenerated cellulosic pulp has fibres with lower length and strength compared to the feedstock. Thus, mixing the recycled material with virgin material helps improving the performance of the yarn containing recycled cellulosic fibres.

In chemical recycling of synthetic fibres, a different output is obtained processing polyamide-rich textiles via chemical recycling for nylon 6 (PA6 – polyamide), where the monomers can be further processed to build a synthetic fibre with characteristics comparable to the virgin material (**Table 12**).

Table 12 shows that blends are still difficult to recycle – only wool recycling using hydrochloric acid and depolymerisation techniques processing PA6 are implemented at scale. This represents a big technological challenge that should be addressed because the majority of textile apparel placed on the EU market is made with blends of natural and chemical fibres (48-60%). Single-fibre products account for smaller shares: 18-28% made of cotton, and 11-17% made of polyester (Refashion, 2023; Bakowska et al., 2025).

This analysis allows to better understand information reported in Table 16 of the 1st milestone, which shows that recycled fibres represent a very low share of the market and that the most recycled ones are wool (7%), polyamide (PA) (2%), cotton (1%), and MMCF (0.5%). Polyester is not included in this list because polyester fibres of recycled origin are currently manufactured from PET derived from packaging (separately collected plastic beverage bottles).

Currently, the type of textile waste processed for the production of recycled fibres is mainly post-industrial. Also pre-consumer waste is used, but in lesser quantity. This happens because these types of waste:

- Are available at manufacturing or retailing sites, thus they are already segregated from other waste fractions;
- Do not need to be sorted, because they already are when generated;
- Are constituted by undamaged and clean fibres;
- Have known composition.

In particular, post-industrial waste has no non-textile parts and is often free of coatings and other disruptors for the most used recycling techniques. This means that it can often be further processed without prior pre-treatment.

Conversely, post-consumer waste has largely not been used as feedstock until now because its treatment is more challenging and expensive than the other waste types. The reasons for this are that: (1) post-consumer textile waste needs to be segregated from other waste fractions and sorted; (2) fibres are damaged, which would result in less performing mechanically recycled fibres; (3) requires fibre and chemical composition to be analysed – see sorting techniques. Although post-industrial and pre-consumer textile waste are currently the cheapest option, the resulting recycled fibres are still more expensive than virgin fibres.

At present, textile products including recycled fibres report their recycled content either via a manufacturer declaration, or via a third party verification system. Since there is no laboratory test capable of determining the recycled or virgin origin of fibres, the only possible verification tool has to rely on chain of custody systems.

The study of the literature and the preliminary exchange with stakeholders revealed that designers and recyclers have apparently opposite needs. The former uses fibre blends, dyes, coating and other current recycling disruptors to improve the performances of the textile product and simultaneously meet the taste of the users, who would like to buy products at low price (see section 1.2.1.1). The latter, due to the current status of recycling techniques (see **Table 12**), would need to process textile products made with only one fibre and carrying a minimum amount of disruptors.

Business models and user behaviour

A recent analysis performed by the JRC reported that recycling is not adequately in place and that the lack of a strong business case for recycling has negative effects on the business case of other economic actors in the recycling system, such as collectors and sorters (Huygens et al., 2023).

The main barrier to the development of a market for recycled fibres results from the general low cost of products: from the raw material to the final product placed on the market. Textile products containing recycled fibres are more expensive than the same products made only of virgin fibres. The research conducted by the JRC found that the insufficient internalisation of externalities in the global textile supply chain produces economic market barriers to recycling. Therefore, the economy of scale for the establishment of a profitable recycling system is challenged due to (Huygens et al., 2023):

- Technical limitations in recycling techniques (see **Table 12**);
- The design of non-recyclable textile products (technological externalities);
- Risk aversion to adopting recycled fibres by the next value chain user (consumption externalities);
- The cost associated to the identification of feedstock characteristics suitable for the specific recycling technology.

Despite the problem highlighted above, there are some fashion brands promoting the use of textile apparel with recycled content. Additionally, the preliminary exchange with some stakeholders revealed that a few large fashion brands are also promoting the collaboration between designers and operators in the recycling system to design recyclable textile apparel.

With a growing interest in textile products containing recycled fibres, there should be also a growing demand for certification schemes based on chain of custody systems capable of tracking the source of the recycled fibres used.

Users contribute to increasing the demand for textile products containing recycled fibres. The analysis performed in section 6.2.7 of the 1st milestone revealed that it is mostly young and educated individuals usually look for these products. The investigation performed by Pranta et al. (2024) revealed that individuals with higher income have a higher likelihood to purchase textile products with recycled content compared to individuals having a lower-income. This confirms the difficulty of recycled fibres to compete with virgin fibres.

Legislative framework

The legislative framework addressing the recycling system could be described focussing on the types of textile waste.

Post-industrial textile waste is not subject to any specific legislation in the EU nor in producing third countries. The Waste Framework Directive (2008/98/EC) only establishes generic objectives to prevent waste generation but contains no specific provisions addressing this type of waste.

Pre-consumer textile waste is addressed by the ESPR, which prohibits the destruction of unsold textile products in the EU. Only micro and small enterprises will be exempted from this prohibition. However, the ESPR only addresses unsold products in the EU, while it does not address pre-consumer textile waste generated at manufacturing stage in third countries. The authors are not aware of any legislation in third producing countries addressing pre-consumer textile waste.

Post-consumer textile waste is addressed by the Waste Framework Directive (2008/98/EC) and the newly published Waste Shipment Regulation (2024/1157) (WSR) ([22]), regulating the management of post-consumer waste in EU and its potential shipment within the EU and from the EU to third countries, respectively. In particular, the proposal to establish Extended Producer Responsibility (EPR) schemes for textiles in all EU Member States should ensure that producers will cover the costs of textile waste management and research and development on e.g. recycling technologies (see section 4.1.2 of the 1st milestone).

1.2.5.2 How to assess recyclability

The analysis of the ecosystem reported in the section 1.2.5.1 suggests to address recyclability with an integral and dynamic approach assessing the evolution over time of all elements of the recycling system, from the

[22] Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006. Available at this link.

feedstock to all process techniques involved. To this aim, in the framework of this PS, a recyclable textile apparel must have the following five characteristics, which apply as soon as it becomes waste:

1. It can be effectively collected;
2. It can be sorted, i.e. segregated from other textile waste and sent to the subsequent suitable recycling pathways;
3. It can be pre-treated before recycling, or can be sent directly to recycling without specific pre-treatment;
4. Its fibre content can be fully used as feedstock for one or more recycling techniques to produce recycled fibres usable in textile products;
5. It has no elements or substances in amounts that disrupt the collection, sorting, preparation for recycling and recycling, or that limit the use of the recycled fibre.

Therefore, textile apparel that meets all these five characteristics is considered to be recyclable, otherwise it is not recyclable. This integrated approach was chosen to assess the recyclability of textile apparel because all elements in the recycling system are important. This integral approach based on these five characteristics is a similar approach used by the French Law n° 2020-105 ([23]) to define recyclable textile products.

The approach proposed in this PS does not include any geographical limitation of the processes involved, because it assumes that the recycling system will comply with the provisions on environmentally sound management of waste under the WSR, where it is required that the requirements applied in the country of destination ensure a similar level of protection of human health and the environment than the requirements stemming from Union legislation. Moreover, it does not refer to specific characteristics of the feedstock or particular process techniques, because it aims to promote the technological evolution from the perspectives of the product design, sorting and recycling techniques.

Point 4 of the approach guarantees the successful application of the recycled fibre into any textile product. This choice takes into account: (a) the objective of the Textile Strategy to close the loop of materials in textile products, (b) the current technological limitations described in section 1.2.5.1, and (c) the fact that the application of recycled fibres into textile apparel will be described/promoted via the recycled content (see section 1.2.5.4).

Despite its integral and dynamic nature, this approach is in line with the generic definition of recyclability reported in section 1.1, which is inspired by the WFD. Moreover, this approach is applicable in the same way to all products in the scope of the PS, making no necessary any categorization in the context of recyclability.

On the assumption that mandatory EPR for textiles based on the Commission proposal to amend the WFD is adopted, upon its entry into force, it will support this integrated approach because economic operators (i.e. fashion brands and retailers) placing products on the EU market would pay eco-modulated fees to support the waste management of textile apparel. It is envisaged that eco-modulation of EPR fees for textiles will be based on future ecodesign criteria, which could include recyclability requirements. In this framework, designers and economic actors of the recycling system will be invited to work side-by-side to place on the EU market recyclable products.

The proposed approach will need to be complemented by a standardised verification system assuring that the textile apparel indeed complies with the five characteristics reported above.

1.2.5.3 Description of the product technologies in the context of recyclability

In the framework of recyclability, the product technologies could be described as follows.

- BC are not recyclable;
- BAT are products that currently can be processed by techniques reported in **Table 12**, which are implemented at scale, i.e. (1) single-fibre textile apparel recycled with mechanical recycling, (2) pure cotton textile apparel recycled with chemical recycling for the production of MMCFs, (3) PE6-rich textile

[23] LOI n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire. Available at this link. Last accessed on 22 October 2024.

apparel recycled with chemical recycling for synthetic fibres, and (4) wool-rich blends recycled with chemical recycling based on hydrochloric acid.

- BNAT are products that can be processed with techniques at intermediate maturity level reported in **Table 12**.

However, the definition of these BAT and BNAT establishes some biases in terms of fibre composition and absence of specific components or substances in the product, which does not reflect the technological neutrality pursued in this PS. The development of design options in Task 6 will address this lack of technological neutrality.

1.2.5.4 How to assess recycled content

The analysis of the ecosystem related to recyclability and recycled content suggests to connect the assessment of the recycled content with the recyclability of the textile apparel and with the type of textile waste treated. The assessment takes into account two main aspects:

1. The availability of recyclable textile apparel, which implies the production of a recycled fibre with performances suitable for the use in textile apparel;
2. A verification system capable to track fibres coming from post-consumer textile waste.

The first aspect is very much connected to the definition of recyclable textile apparel reported in section 1.2.5.2. This connection allows to close the loop for fibres used in textile apparel and guarantees the availability of recycled fibres. Only if recyclable textile products are placed on the market, there will be availability of recycled fibres to be used in new items. In particular, the reference to the performance of recycled fibres takes into account the technological developments in spinning techniques, which over time will be capable to spin fibres with lower performances.

The second aspect narrows down the type of textile waste that can be used to produce the recycled fibres. **Table 13** reports a description of the three types of textile apparel waste in the context of recyclability and recycled content. Although post-industrial and pre-consumer textile waste have evident technical advantages when they are used to produce recycled fibres, they are often the result of overproduction, overconsumption and can be also attributed to inefficiencies in the production system (section 1.2.4.2). The inclusion of post-industrial textile waste as a source of the recycled content for new textile apparel could incentivise the generation of this type of waste. Furthermore, this textile waste type is also the only one that is not specifically regulated (**Table 13**).

The second aspect excludes the use of pre-consumer waste because its generation is not fully regulated. When it is generated at manufacturing stage outside EU, it is not addressed by any legislation. When it is generated at manufacturing and retailer stages in EU, it is addressed by the ESPR, which forbids the destruction of unsold textile products in the EU. However, the ESPR does not address pre-consumer waste generated by micro and small enterprises. Also the inclusion of these types of textile waste as the source of the recycled content of a new item would incentivise their generation especially when it occurs at manufacturing stage outside EU (**Table 13** and section 1.2.4.2). Sections 5.1 and 5.2 in the 1st milestone reports that the largest majority of the EU consumption is affected by the production occurring outside EU.

Therefore, in the framework of the PS, the definition of recycled content should be narrowed down compared to that reported by the ISO 14021 and used in section 1.1. Following the two aspects reported above, *the recycled content is the proportion, by mass, of recycled fibres coming from recyclable textile apparel disposed of as post-consumer waste*.

The recycled content of a new textile apparel is fibre-specific, and it is also specific to the function that the item must provide. For this reason, all products included in scope are described by the framework reported in this section. A categorization of the products in scope based on the types of fibres and the specific function to be provided by the item would result in a disproportionate number of categories, which would not meet the aims of the PS.

Table 13. Description of the textile apparel waste in the context of the recyclability and the recycled content

Characteristic	Post-industrial	Pre-consumer	Post-consumer
Status of the material	Undamaged and clean fibres.	Undamaged and clean fibres.	Worn material with damaged fibres. It is often relatively dirty, with various form of stains and moist content, generating mould and hygienic problems.
Non-textile components	Absent	Present	Present
Knowledge of fibre composition	Known and detailed by the manufacturer.	Based on what is reported on the label in accordance with the TLR. The reading of one label allows the identification of fibre composition of the entire collection.	Based on the analysis of the item's surface via infrared spectroscopy.
Degree of heterogeneity	Very low – homogeneous waste	Low	Very high
Location of generation	Manufacturing stage (available in producing countries, which are mainly countries in Asia - see sections 5.1 and 5.2 in the 1st milestone)	- Manufacturing stage (available in producing countries, which are mainly countries in Asia - see sections 5.1 and 5.2 in the 1st milestone) - Retail stage (available in EU)	User stage (available in EU)
Sorting	Not always needed, because it is already sorted in the moment of generation.	Not always needed. - Products belonging to collections that not reach the customer are already sorted; - Returned products could need some sorting depending on the retailer logistic.	Needed
Pre-treatment	It is ready for recycling because it includes mainly cuts of fabrics. Potentially, only shredding is needed.	Needed	Needed
Regulating legislation	Most of the production occurs in Asian countries, where the authors did not find any legislation addressing the generation of this type of waste. Very little production occurs in EU. The generation of post-industrial waste generated in EU are not specifically regulated. The WFD sets only generic objectives to prevent waste generation. The shipment of post-industrial waste generated in EU is subjected to the WSR. The material described here as post-industrial waste could in some Member States be also identified as a by-product, which would put it out of the scope of the WSR.	Waste generated at manufacturing stage: - Not addressed by any legislation identified by the authors if production occurs outside EU; - Addressed by the ESPR, which bans destruction of unsold products, with exemption only for micro and small enterprises. Waste generated at retailer stage are addressed by the ESPR, which bans destruction of unsold products, with exemption only for micro and small enterprises. The shipment of post-industrial waste generated in EU are subjected to the WSR. However, unsold products that did not become waste are outside the scope of the WSR.	This type of waste is fully generated in EU and is addressed by the WFD (EPR and EoW), and the WSR.

TLR: Textile Labelling Regulation (1007/2011)
ESPR: Ecodesign for sustainable Product Regulation (2024/1781)
WFD: Waste Framework Directive (2008/98/EC)
EPR: Expended Producer Responsibility, under the WFD
EoW: End-of-Waste criteria, under the WFD
WSR: Waste Shipment Regulation (2024/1157)
The analysis does not include transportation of the waste because it depends on the location of the treatment facilities.

Source: own production

1.2.5.5 Description of the product technologies in the context of recycled content

In the framework of the recycled content, the base case of the product technologies would have no recycled content (see Table 16 of the 1st milestone). Differently, the identification of BAT and BNAT should distinguish fibres and product functions.

In general, when constructing fabrics, knitted products are generally better suited for incorporating mechanically recycled fibres due to their more flexible structure compared to woven fabrics (Boschmeier et al., 2024). However, a notable exception is represented by denim trousers, which can incorporate up to 20% post-consumer recycled material (Kuppen, 2024).

1.2.6 Environmental impacts

The product aspect on 'environmental impacts' is defined as any change to the environment, whether adverse or beneficial, wholly or partially resulting from a product during its life cycle.

This section analyses the elements affecting the environmental impacts generated by the consumption of textile apparel in EU to best describe the product technologies. Therefore, the analysis reported in this section does not aim to give a comprehensive overview of the environmental impacts caused. Task 5 of the PS will include a comprehensive environmental assessment of the base case of products included in the scope.

1.2.6.1 The ecosystem affecting the environmental impacts

Process techniques

For each stage of the life cycle of the product, there are numerous process techniques that contribute to the product development. Each of those techniques have different environmental performances. Therefore, the choice of process techniques plays a key role in the environmental impacts of textile apparel.

Different levels of environmental impacts, related to specific process techniques, can be seen in production stages such as yarn manufacturing. A range of spinning techniques is available. Ring-spinning is the most commonly used in the textile industry due to its versatility in terms of the range of fibres that can be processed. Its main advantage is that it produces finer and stronger yarns than other spinning techniques due to good fibre control, orientation and alignment during spinning. However, it has high rates of power consumption, caused by the necessity of rotating the bobbin at a rate of one turn for each twist inserted. In contrast, open-end spinning was developed in an attempt to overcome the speed limitations of ring spinning. Another advantage is a reduction in energy consumption (Elhawary, 2015a). In the case of wool spinning processes, significant differences can be seen between fabric derived from carded yarn (woollen process) and fabric manufactured using combed yarn (worsted process) in terms of the quantity of lubricants applied, with 5% in the former and 2% in the latter (Roth et al., 2023).

Knitting is a mechanical process and involves knotting yarn together with a series of needles. The main knitting production methods are straight knitting, fully fashioned knitting, integral knitting, and complete textile apparel knitting. Straight knitting most commonly relies on the weft technique, which consists of using one continuous yarn which is fed to and looped in rows by one or more needles at a time. Fully fashioned knitting machines can produce custom-shaped sheets of fabric by adding/removing the stiches, so that there is little or no need for cutting panels, reducing the amount of discarded material. Integral knitting is an advancement of the fully fashioned knitting technique. An integral knitting machine is able to add additional trimmings as an integrated part of the fabric panel, reducing fabric losses from cutting, as well as sewing requirements. Finally, complete textile apparel knitting machines are able to knit complete textile apparel, eliminating the cutting and sewing steps altogether, decreases raw material consumption and producing higher-quality textile apparel (Roth et al., 2023).

Another example of these differences can be seen in the dying process, in this case in terms of water consumption. In batch dyeing, a certain amount of textile material is loaded into a dyeing machine and brought to equilibrium with a solution containing the dye and the auxiliaries. An important parameter in dyeing is the liquor ratio of the equipment: the weight ratio between the total dry material and the total liquor (a liquor ratio of 1:10 means 10 litres of water for 1 kg of textile material). This parameter not only influences the amount of water and energy consumed in the dyeing process, but also plays an important role in the level of exhaustion of the dye and in the consumption of chemicals and auxiliaries. Dyeing machines vary greatly in their liquor ratios, depending also on the type of substrate to be dyed and its hydrophilicity. For instance, in woven and knitted fabrics, liquor ratios can vary from 1:2 in airflow equipment, to 1:40 in winch beck equipment (Roth et al., 2023). These differences will significantly influence the environmental impacts of final products. Dyeing can also be carried out in batch or in continuous/semi-continuous mode. Batch dyeing processes generally require higher water and energy consumption than continuous processes. Continuous and semi-continuous dyeing processes consume less water, but this also means a higher dyestuff concentration in the dye liquor.

The term finishing covers all those treatments that serve to impart to the textile the desired end-use properties. These can include properties relating to visual effect, handle and special characteristics such as water and fire proofing. Finishing may involve mechanical/physical and chemical treatments. Among textile finishing processes, chemical ones are the most significant from the point of view of the emissions generated. As in dyeing, the emissions are relatively different between continuous and discontinuous processes. Continuous finishing processes do not require washing operations after curing.

Finally, in terms of waste management techniques, a number of options are available, from landfilling and incineration, to mechanical recycling. In this case, as reported in Solis et al. (2024), recycling is a preferred pathway for most of the environmental impact categories.

In essence, the wide variability of process techniques available to manufacture textile apparel has a fundamental relevance on the environmental impact of final products.

Business model of economic operators in the ecosystem

Companies have multiple choices in the definition of their strategies and business models. These choices imply different levels of environmental impact of the final product.

As described in section 5.5 of the 1st milestone, two main models can be identified in the textile apparel industry (DG GROW, 2021). A consumer-led model, where the requests of the consumer are the centre; and a brand-led operation model, where the brand dictates the design and the manufacture. Other classification of business models can also be made. For instance, in terms of supply chain approach. On one hand, there is the integrated approach, where the production is entrusted to internal suppliers and the logistics aims to quickly react to customers' demands. On the other hand, there is the centralised approach, where the production is mostly outsourced and supported by audit and quality control programmes. Hybrid versions of those business models can also be found. Each business model has different characteristics, each of them with different implications on the environmental impact of products. In this section, a brief description of these characteristics is made.

The trend turnover is a fundamental factor that defines a business model. Some companies opt to implement business models characterised by continuous novelty and disposable trends in constant change (Centobelli et al., 2022), designing their products for rapid trend turnovers through obsolescence and early disposal. Other companies, in contrast, implement business models with less frequent trend turnovers, focusing on product durability and reverse logistics. The number of seasons or trends that are placed on the market largely affects the environmental impacts. Rapid trend turnovers tend to drive consumers (directly or indirectly) to replace clothes, even when it is still not necessary from technical perspective.

Related with trend turnover is production time, which refers to the time between the design of the product and the availability of such product for the consumer. Production time largely affects several aspects of the supply chain, from procurement to manufacturing capacity, planning and inventory management. Shorter production times increases the probability of manufacturing errors. This also increases the generation of waste, due to the required destruction of products that cannot be sold (see section 1.2.4). Shorter production times also requires the use of air transport, rather than cargo ships, increasing the environmental impact of the distribution stage.

The location of different stages of the supply chain also affects the environmental impact of products. Many companies outsource the transformation process of raw materials into completed textile apparel to third countries, often to allow access to low-cost labour and less stringent environmental regulations, such as water or air emission levels which are less ambitious than in the country of origin (Centobelli et al., 2022). If the numerous stages of the supply chain are scattered over the globe, more transport is required, increasing the environmental impact of the distribution stage.

The location of different stages of the supply chain also affects the energy source used to produce textile apparel. The manufacturing of textile apparel is energy intensive. Each country has a different energy mix ([24]) that has a significant influence on the impact of the final product.

[24] A different combination of energy sources to produce electricity

Different environmental impacts can also be expected, related with the ownership of the apparel. There are companies that opt for renting products rather than selling them to individuals. When a product is rented, it has the possibility to be used by more consumers. This is particularly true for products that are not used very frequently –such as gala dresses- or for products that quickly become unusable –such as clothes for children-. In principle, products sold under this business model (sold as a service rather than a product) produce lower environmental impacts, due to the higher intensity of use among different users across their lifetime.

Textile apparel that is commercialized as a service (rented, shared, etc.) will need higher levels of physical durability, which can require for example a more dense fabric with higher amount of fibres and electricity compared to products with lower performances. This, among other process techniques imply different levels of environmental impacts of the final product.

In essence, decisions made by companies in terms of the business model implemented to place textile apparel on the market have a significant relevance on the environmental impact of the final product.

User behaviour

User behaviour is an important aspect that affects the environmental impact of textile apparel.

Consumers influence the environmental impact of clothing when they make purchase decisions. Apparel is often bought spontaneously, simply because leisure and fun are associated with the act of buying clothes. Only a minority of consumers inform themselves correctly before buying apparel (Kleinhückelkotten et al., 2018). When a consumer chooses to acquire a product that has been placed on the market under a business model based on fast trend turnovers and short production times, they are contributing –possibly unknowingly- to the environmental impacts associated with that business model. The amount of products that are purchased also influences overall environmental impact of clothing.

Consumers also have an influence on the environmental impact of textile apparel, depending on the way they use and maintain these products. Using clothes in the right environment contributes to increase their lifespan. Storing and folding apparel may also have an influence on the lifespan of apparel, since it may affect their intrinsic quality.

Related with product use are the unwritten social rules that govern specific gatherings, such as workplaces, celebrations such as weddings or regional festivities that last several days. In these events, it is expected that attendees will not wear the same apparel on different days. The expectation is that different apparel will be worn on different days, even when it is not necessary from technical point of view. This contributes to an increased consumption and production of textile apparel, and therefore to their environmental impact.

Maintenance activities can also contribute to increase lifespan of products and avoid (or delay) the acquisition of new products, minimising the overall environmental impact. Clothes must be sorted appropriately before washing to avoid premature deterioration. On occasions, consumers use quantities of detergent and softeners which are merely based on their perception, rather on manufacturers' recommendations (A.I.S.E, 2017), potentially increasing the impact of the product use stage. In terms of washing, water temperature and washing frequency are not always optimised, contributing to an excessive consumption of energy. Drying can be performed either naturally or using dryers, a choice which is highly related with user choice, availability of space in the household or geographic location. The choice of clothes that do not need ironing –or that require less frequent ironing- can also have an influence on the environmental impact of the final product.

Consumers also have an effect on the environmental impact of textile apparel when they make decisions related with its end of life. As pointed out in section 9.6.3.1 of the 1st milestone, this is influenced by the individual characteristics of the consumers, their habits, demographic context, product traits and perceived quality (Cluver, 2008; Goworek et al., 2020). Perceived quality of the product is a decisive factor to discard textile apparel (Aakko and Niinimäki, 2021). Low perceived quality also triggers early disposal (Piippo et al., 2022). This is also magnified by the loss of symbolic value given by the consumer (Gwozdz et al., 2017). Discarding products when they are still technically functional increases their environmental impact, due to a low intensity of use.

In essence, user behaviour of textile apparel can have a significant relevance in the environmental impact of final products.

Legislative framework and industrial best practices

The legislative framework has an influence as well on the environmental impact of final products.

In the EU, the Industrial Emissions Directive aims to reduce industrial pollution by requiring industries to adopt preventive measures and use the best available techniques (BATq). It mandates integrated permits covering all environmental impacts and sets strict emission limits for key pollutants. This Directive applies to the manufacturing of textile apparel. The BAT for the textiles industry are described in the Best Available Techniques Reference Document (Roth et al., 2023). The end of life is addressed in the Best Available Techniques Reference document for Waste Treatment (Pinasseau et al., 2018).

As pointed out in section 5.7 of the 1st milestone, countries outside of the EU tend to have less stringent measures about environmental protection, in particular on emission limits for key pollutants. The EU has the most ambitious legislative framework worldwide, covering aspects such as emissions to air and water, energy consumption and energy efficiency, water use, waste generation, and usage and management of chemicals. Comparing this framework with that of China, the top global exporter of apparel, it can be seen that the latter only addresses emissions to air and water as well as waste generation. In contrast with the EU BREF, the Chinese framework also covers noise emissions. With regards to India (the fifth global exporter of apparel), only emissions to water are addressed. The full comparison of aspects covered in different Best Available Techniques reference documents around the world can be seen in Table 26 of the 1st milestone.

A comparison in terms of specific substances is made in **Table 14**. The emission levels to water of three substances/parameters are compared: chemical oxygen demand (COD), chromium and zinc (the comparison of values on emissions to air was not possible due to different practices and key environmental indicators used in the different frameworks). In **Table 14** it can be seen that there are significant differences in the level of ambition between the EU, China and India.

Table 14. Environmental performance levels for emission into water in specific regions

Key Environmental Indicator	EU	India	China
COD (mg/l)	40-100	100	7-30 000
Chromium (mg/l)	0.01-0.1	2	n/a
Zinc (mg/l)	0.04-0.5	n/a	n/a

n/a: Not Addressed

Source: own production based on section 5.7 and 9.5.2 of the 1st milestone

The EU BREF sets the emission limits on COD between 40-100 mg/l for all activities and processes, whereas in India and China those limits are set at 100 mg/l in the former and between 7-30 000 mg/l in the latter. In the case of chromium, China does not establish a limit. The EU limit is established between 0.01-0.1 mg/l, more ambitious than the 2 mg/l set in India. In terms of zinc, only the EU establishes a limit value, between 0.04-0.5 mg/l.

These differences are particularly relevant for textile apparel, since most of the activities related with raw material production and manufacturing occur out of the EU (in countries such as China or India). Deciding to manufacture products outside of the EU means that the emission levels of manufacturing plants will be subject to less stringent emission requirements. Therefore, considering the relevance of the manufacturing stage in textile apparel, producing textile apparel outside of the EU increases the environmental impact of the final product. Moreover, companies producing textile apparel in the EU must face higher costs than companies producing outside of the EU, due to the prevention and reduction of emission activities that they need to implement.

1.2.6.2 How to assess the environmental impacts and description of product technologies

The analysis of the ecosystem affecting the environmental impact of textile apparel shows the difficulty to identify in a rigid framework the characteristics of specific product technologies. However, the information gathered in the previous sections allow to build a reasonable picture.

The BC takes into account that China, India, and Bangladesh manufacture the largest part of textile apparel consumed in EU. This means that the BC is described by process techniques adopted in these countries, where the legislation allows higher emission into the environment compared to what happens in EU. The business model that characterises the BC promotes overproduction and overconsumption, supported by users that tend to change frequently their wardrobe. The end of life of the BC is described by landfilling and incineration of textile waste in the EU as well as in third countries.

The BAT takes into account EU manufacture and the currently available less-impacting business models, user behaviours and waste management options. This means that the BAT is described by process techniques adopted in EU and described in the EU-BREF. The business model that characterises the BC promotes a production rate similar to that before 2004, when the apparent consumption of EU was about half of the current one (Figure 7 in section 5.2 of the 1st milestone). The end of life of the BAT is described by energy recovery and recycling in the EU of the textile waste.

Since the environmental impacts are affected by very numerous aspects, the description of BNAT will be simply more ambitious than BAT and will take into account all the BNAT reported for other product aspects.

This description of the product technologies is suitable for all products in the scope of the PS.

1.2.7 Presence of substances of concern

Substances of concern are defined in Article 2(27) of the Regulation and largely encompass substances that are of concern due to their negative effects upon the health of humans and to that of receptors in the environment as a consequence of their adverse long-term effects. These substances are specifically identified via being listed as (a) Substances of Very High Concern (SVHCs) in the REACH "Candidate List", (b) by having a harmonised classification under specific hazard classes defined in the CLP Regulation or (c) by being identified as Persistent Organic Pollutants (POPs) by the POPs Regulation. In addition a specific class of SoCs are defined in ESPR, which (d) hinder reuse and recycling (of materials in the product in which SoCs are present) and which should be identified in the product-specific delegated acts to be developed under ESPR. It is worth noting that a single substance could potentially be identified simultaneously under several SoC classes (a, b, c and d).

1.2.7.1 Ecosystem of Substances of Concern

Manufacturing factors and process techniques

A very large variety of chemical substances are used by the textile sector in the different manufacturing stages, from fibre production, to spinning, weaving or dyeing and finishing of fabrics, to name just a few of the many processes involved. Chemicals are used to make fabrics more durable, softer or to provide colour and colour-fastness or a water or stain-repellent finish, among many other uses. Some chemicals are specific to the different fibres used to make textiles (cotton, polyester, wool, etc.).

It is not a simple task to determine the number of chemicals used by the textile sector, given the large variety of processes in which these are used, the multitude of functions they provide and the global distribution of chemicals supply chains and textile manufacturers. Roos et al. (2019) claim that the number of chemicals in use in the textile industry exceeds 15 000, with over 10 000 dyes and pigments and about 5 000 auxiliary chemicals, quoting figures from the Colour Index ([25]) and TEGEWA ([26]), respectively. A recent report[27] on the use of PFASs in the textile sector indicates that more than 8 000 chemical substances are used by this sector. Regardless of which the precise figure may be, the sheer numbers involved provide an indication of the magnitude of the challenges that the sector faces in implementing supply-chain transparency and traceability of chemicals.

Although it is acknowledged that chemicals play an essential role in achieving a competitive textile apparel sector that satisfies the demands of consumers, reports such as that by the Swedish Chemicals Agency, that investigated 2 450 substances used by the textile sector and found 750 classified as hazardous for human health and 440 as hazardous for the environment, are a cause of concern (KEMI, 2014). As for other material streams, it is also acknowledged that legacy chemicals may be reintroduced back into the economy via recycled fibres.

Similarly, a recent report by the European Environment Agency([28]) on per- and polyfluoroalkyl substances (PFAS) highlights the specific concerns that this group of substances pose both due to their health and environmental impacts as well as because of their consequences on circularity. According to this study, it is estimated that textiles account for approximately 35% of the total global fluoropolymer demand and that a

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[25] https://colour-index.com/

[26] Textiles Auxiliaries e-market. https://www.thk-online.net/

[27] A Review of PFAS as a Chemical Class in the Textile Sector. Natural Resources Defense Council, 2021. https://saicmknowledge.org/library/review-pfas-chemical-class-textiles-sector-policy-brief

[28] EEA 2024. Briefing no. 11/2024. PFAS in textiles in Europe's circular economy. https://www.eea.europa.eu/en/analysis/publications/pfas-in-textiles-in-europes-circular-economy

third of all PFAS in the EU (41 000 – 143 000 tonnes) are used in the textile sector, which is thereby estimated to be the biggest contributing use sector to PFAS pollution in Europe. Furthermore, in its report on textiles, published in the year 2017, the Ellen McArthur Foundation stated:

"*The use of substances of concern in textile production has negative effects on farmers, factory workers, and the surrounding environment. While there is little data on the volume of substances of concern used across the industry, it is recognised that textile production discharges high volumes of water containing hazardous chemicals into the environment. As an example, 20% of industrial water pollution globally is attributable to the dyeing and treatment of textiles*" (Ellen MacArthur Foundation, 2017).

In this report a call for action is made in moving towards a new textiles economy, requiring, as regards substances of concern, to develop "*a robust evidence base on the usage of chemicals, including the amount used, as well as identification of substances of concern and the impacts of these*".

User behaviour

Section 6 of the 1st milestone reports information available on behavioural trends among users with regards to textile apparel. It covers aspects that include the way users choose to buy apparel, their habits during the use phase, and why they decide to dispose of them. It also distinguishes user behaviour aspects at pre-purchase, post-purchase and disposal stages.

In a survey spanning 27 EU Member States, 60% of 26 718 respondents perceive chemicals in apparel fabrics as minimally risky, with most not seeing them as a threat to people whereas, looking at the country level, health risks are deemed very important by about two-thirds of respondents in Germany and Slovakia whereas respondent in Denmark and the UK attributed a lower importance to this aspect (European Commission, 2009). Similar conclusions can be derived from a survey by Fashion Revolution (2020) which indicates that only about 37% of respondents in United Kingdom, France, Germany, Italy, and Spain considers it important to buy apparel produced without harmful chemicals.

Despite the uneven level of concern by users regarding chemicals in apparel, especially as regards substances that pose a risk to human health or to the environment, the establishment of information requirements under ESPR on the presence of substances, in particular of substances of concern in apparel will contribute to the generation of information that can further provide transparency to enable an informed public opinion. This in turn can inform possible actions that could be addressed in specific legislation on the safe use of chemicals such as REACH.

Business models

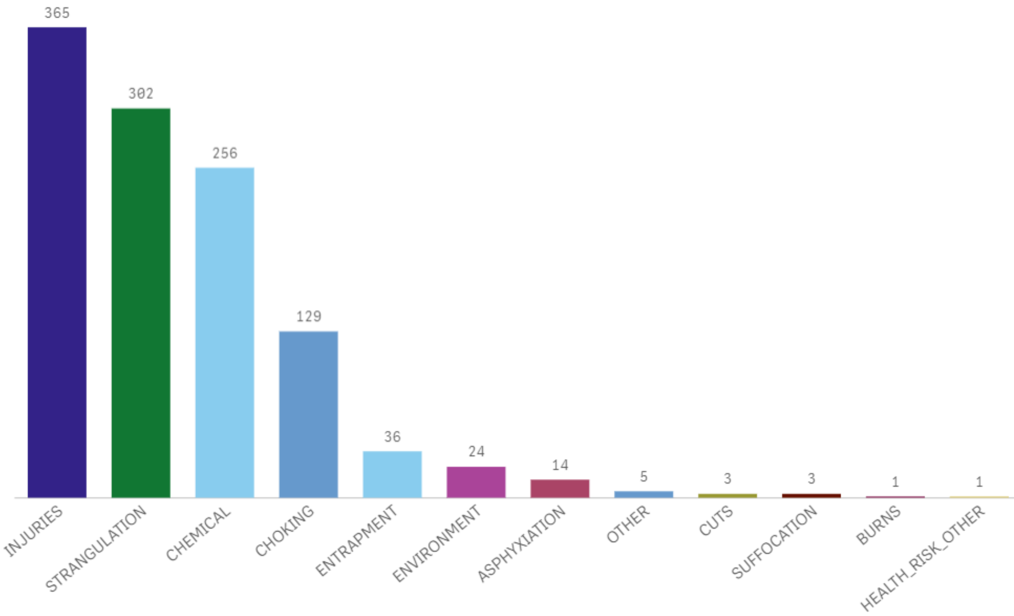
The high throughput business models, already mentioned in previous sections, result in very short textile apparel manufacturing times, with the appearance of dozens of collections every year and where manufacturing occurs largely out of the EU. This model based on production happening largely out of the EU also has consequences related to the use of chemicals, given regulations on the use and management of chemicals differ, as do levels of enforcement, control and monitoring. According to Niinimäki et al. (2020), the majority of the chemicals use connected to producing textiles for the EU occurs outside the EU.

Although it is not possible to pin-point impacts of the business model on specific chemicals, it seems clear that the large increase in production, taking place in third countries where often legislation and environmental controls and less stringent than in the EU, results in increased emissions of chemicals, notably via waste water during dyeing and washing processes, and can result in the use of substances that are regulated in the EU and other constituencies, which subsequently risk entering these markets, incorporated within textile products. Ogugbue and Sawidis (2011) state that some 0.7 million tons of synthetic dyes are produced annually worldwide and that the textile industry releases up to 200 000 tons per year of these dyes via effluents resulting from inefficient dyeing and finishing processes. Most of these dyes escape conventional wastewater treatment processes and persist in the environment. Evidence of the use of regulated hazardous substances in textiles, and of their presence in products imported into the EU can be found consulting alerts in Safety Gate([29]), the EU rapid alert system for dangerous non-food products, where reports of textile apparel and footwear items can be found containing Chromium VI, nickel, different phthalates, cadmium and other regulated substances.

[29] https://ec.europa.eu/safety-gate-alerts/screen/search?resetSearch=true

An analysis of the total alerts registered in Safety Gate in the period 2019 – 2023 for the product category “Clothing_textiles” indicates that chemical risks are the third most frequent risk reported (22.5%).

Figure 6. Risks associated to textile apparel



Source: EU Safety Gate statistical tool. Available at this link. Last accessed on 13 November 2024

Legislative frameworks and industrial practices

As indicated in section 4.1 of the 1st milestone, currently there is no specific EU legislation addressing the mandatory sustainability of textiles, but EU Ecolabel criteria for textile products ([30]) exist, this being a voluntary scheme for companies willing to show the good environmental performance of their products. Article 6(6) and 6(7) of the Ecolabel Regulation (EC) No 66/2010 specify that the Ecolabel may not be awarded to products containing substances classified under CLP as toxic, hazardous to the environment, carcinogenic, mutagenic or toxic for reproduction or containing substances meeting the SVHC criteria defined in Article 57 of REACH. Derogations from this prohibition are possible except for substances identified as SVHCs and thereby listed in the so-called “Candidate List” established under REACH. The specific implementation of these general provisions into chemical-specific criteria applicable to textiles are developed as criteria 13 and 14 of the EU Ecolabel criteria for textile products enacted in Commission Decision 2014/350/EU and in the restricted substance list defined in its Appendix 1 and the list of restricted dyes specified in its Appendix 2.

More specifically as regards limitations on chemicals, the REACH regulation has the main purpose of ensuring the safe use of chemicals in the EU. REACH regulates, amongst many other aspects, the restriction of the placing on the market and use of certain substances listed in its Annex XVII, including in some cases, the incorporation of substances into articles. The authorisation title of REACH applies to the placing on the market and use of substances of very high concern (SVHC), aiming at their progressive substitution by less hazardous substances or technologies and by subjecting their use to specific conditions.

A number of restrictions in Annex XVII to REACH specifically mention textiles in their scope. These include entries: 4 - Tris (2,3 dibromopropyl) phosphate; 7 - Tris(aziridinyl)phosphinoxide; 8 - Polybrominatedbiphenyls; 18 - Mercury compounds; 20 - Organostannic compounds; 43 - Azocolourants and Azodyes; 46/46a - Nonylphenol and Nonylphenol ethoxylates; 47 - Chromium VI compounds (relevant to leather articles); 68 - C9-C14 PFCAs and 72 - CMRs in textiles and footwear.

[30] EU Ecolabel criteria for textile products. Commission Decision of 5 June 2014 establishing the ecological criteria for the award of the EU Ecolabel for textile products. Commission Decision (2014/350/EU). Available at this link.

Other restrictions, of general application to articles placed on the market for supply to the general public, or covering all articles placed on the market, may also apply to textile articles, for instance entries 50 – (certain) polycyclic aromatic hydrocarbons; 51 and 52 (certain phthalates); 61 - Dimethylfumarate; and 63 – Lead and its compounds.

Article 33 of REACH sets up a supply chain communication duty requiring suppliers of articles containing SVHC above 0.1% to communicate certain information to the recipients of those articles. Furthermore, Article 9 of the Directive 2008/98/EC, the Waste Framework Directive, promotes the reduction of the content of hazardous substances in materials and products by defining a reporting obligation that apply to suppliers of articles (as defined under REACH), requiring them to provide information regarding the presence of SVHC in articles, including textile articles, pursuant to the referred Article 33, to the European Chemicals Agency (ECHA). This information is collected in the SCIP database ([31]), operated by ECHA, and access is provided to waste treatment operators and consumers.

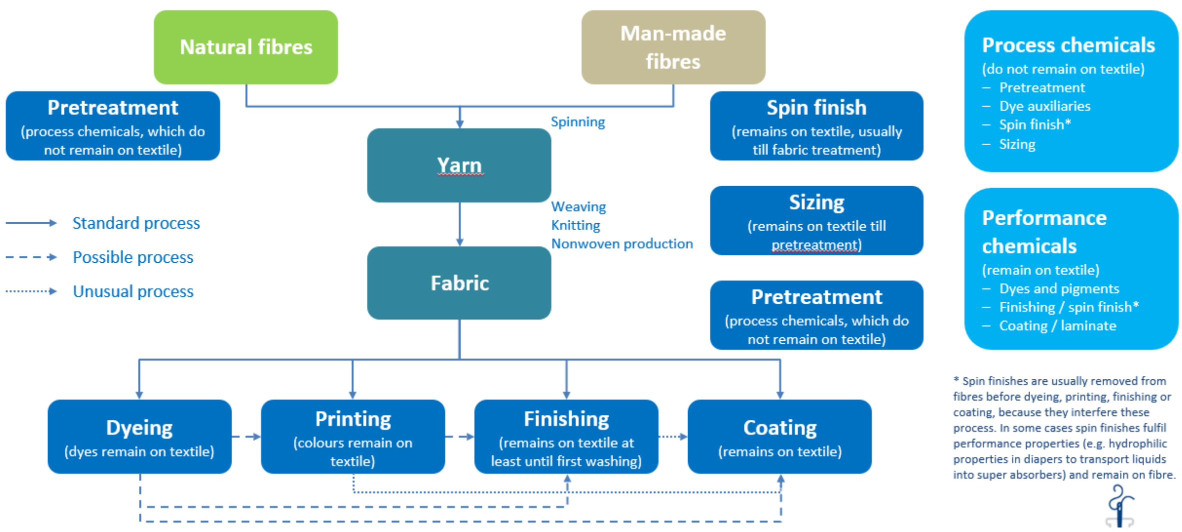
Similarly to REACH, the POPs Regulation regulates persistent organic pollutants with the objective of protecting human health and the environment by prohibiting, phasing out as soon as possible, or restricting the manufacturing, placing on the market and use of substances subject to the Stockholm Convention. Some of these restrictions are relevant to textiles, for instance those associated with certain brominated flame retardants (e.g. certain PBDEs), surface-active substances such as PFOS or PFOA, or substances with biocidal properties such as pentachlorophenol.

Whereas the EU and many developed countries have legislation regulating chemicals, including their use by the textile sector, such legislation does not exist or is less stringent in other countries where textile production takes place. A recent report by Toxics Link ([32]) highlights that "*A review of the global regulatory requirements highlights that there are stringent regulations concerning most of these chemicals only in the developed world, especially in the EU; whereas, regulations on some of the chemicals either do not exist or are less stringent in the developing or emerging economies*".

1.2.7.2 Methodology to assess Substances of Concern

As explained in previous sections, retailers and brands in the textile apparel sector are facing increasing regulatory and reputational challenges to control chemicals present in their products. The sheer number of chemicals involved, the complexity of supply chains and the fact that the majority of processes involving the use of chemicals takes place in third countries, make tracking of chemicals in textiles a complex endeavour. **Figure 7** provides an overview of processes using process and auxiliary chemicals.

Figure 7. Processes using process and auxiliary chemicals



[31] SCIP database from the European Chemical Agency. Available at this link. Last accessed on 13 November 2024.
[32] An overview of toxic chemicals in textiles. Toxics Link 2021. https://toxicslink.org/publications/reports/toxics-chemical-in-textile-report

Source: Adapted from EUCTL - European Chemistry for Textile and Leather, the European Association representing the companies that operate in Europe, producing and putting on the market chemicals used in the textiles and leather value chains.

KEMI (2014) describes the different types of chemicals used in textile production in terms of:

<u>Functional chemicals</u>, which are intended to remain in the final article and are expected to be present at certain concentrations in order to achieve the desirable function. Some examples include:

- Dyestuffs and pigments
- Crease resistant agents
- Anti-shrinking agents
- Oil, soil and water repellents
- Plasticisers
- Flame retardants
- Biocides for defined functionalities in articles, e.g. antibacterial agents
- Stabilisers
- Stiffening agents
- Reactive resins for various finishing treatments

<u>Auxiliary (Process) chemicals</u>, which are involved in some step of textile processing but are not intended to remain in the product. These include:

- Organic solvents
- Surfactants
- Softeners
- Salts
- Acids and bases
- Biocides as preservatives in the process or during storage and transport

<u>Unintended chemical substances - contaminants and degradation products</u>

These are chemicals not intended to remain in the finished article, such as contaminants and degradation products, have no function in neither the textile production process nor in the finished textiles.

- Formaldehyde released from certain reactive resins
- Polyaromatic hydrocarbons (PAH) impurities in pyrolysed products e.g Carbon Black
- Arylamines derived from certain azo dyestuffs and pigments
- Toxic metals (e.g heavy metals) due to impurities from the raw material

Retailers and other operators placing textile apparel on the market have implemented chemical management strategies to enable compliance and to meet their due-diligence obligations as regards chemicals in their products. Effectively there are two types of approaches to obtain information about substances of concern in products.

The **first** relies on **supply chain information** and the implementation of different **supply chain transparency measures**. In this sense retailers and other operators in the supply chain rely on declarations by suppliers, binding contractual terms and third party certification to provide information about substances in products, in particular about those which should not be present in them (positive lists). International and European sectorial initiatives have created relevant Restricted Substance Lists (RSLs) and Restricted Manufacturing Substance Lists (RMSLs) to capture and harmonise reporting of compliance regarding process and auxiliary substances regulated under different legislations and in different countries. Examples of these are the AFIRM Restricted Substances List ([33]) and the ZDHC Manufacturing Restricted Substances List ([34]) used by the textiles and footwear sectors. Other restricted substance-based approaches rely on certification of compliance with the requirements in different ecolabels. The EU Ecolabel for textiles, which has a strong focus on chemicals, as well as the privately managed Oekotex 100 standard for the textile sector ([35]) are examples of this approach.

Broader disclosure approaches for chemicals along textile supply chains, which require a high level of take-up and implementation and the necessary IT infrastructure, in a way not dissimilar to the digital product passport concept introduced under ESPR, have been the subject of numerous studies, pilots and initiatives. In this sense, UN/CFACT has recently provided a recommendation providing industry actors with a set of internationally agreed practices for the harmonized collection and transmission of data for tracking and tracing materials, products, and processes across an entire value chain (UNECE, 2022). Further detailed information on related blockchain based pilot projects, on the developed business requirements specification for traceability and transparency and on the associated data model can be download from the dedicated website ([36]). A number of privately developed traceability information platforms ([37]) focusing on the textile sector are already on the market. The EU funded Interreg project ECHT ([38]), which has the purpose to Enable Digital Product Passports with Chemicals Traceability for a Circular Economy is also relevant.

The **second approach** is **analytical** and relies on direct testing of textile apparel articles to verify the presence and concentration of specific substances of concern. This approach requires the existence of suitable analytical methods for the target chemicals, involves representative sampling of products and is costly. Consequently only targeted analyses have to date been applied to check compliance as regards regulated substances, usually following a risk based approach. AFIRM, ZDHC or the Oekotex standard provide information on available analytical methods for specific substances. Other sources of test method information, for instance as regards substances restricted under REACH, can be found in the Compendium of Analytical Methods recommended by the ECHA Forum to check compliance of REACH Annex XVII restrictions ([39]). Such targeted assessments, checking for compliance of textile products have been carried out under the REACH4Textiles ([40]) project and, more recently, by IKEA and H&M in a project ([41]) focusing on collected textile apparel targeted for fibre-to-fibre recycling.

In general it can be stated that a combination of the two approaches is necessary. Both still have limitations in terms in accessibility of data, costs and capacity, especially for small and medium sized enterprises.

1.2.7.3 Description of product technologies

The use of chemicals in textile apparel manufacture is often related to the specific fibre type as well as to specific finishings (e.g. water-proofing) which are generally not product category specific. Consequently, at this point in the development of the project it is difficult to envisage the possibility of potential information or performance requirements that would be category specific.

Building a base case (BC) and the definition of products representing the best available technology (BAT) is particularly challenging for chemicals, given the large number of substances used by the sector and the lack of quantitative information on the distribution of substances. For certain specific substances and substance families, BAT and BNAT products could potentially be defined in terms of products having switched to non-toxic or less toxic (or in general more sustainable) alternatives – e.g. alternatives to the use of PFAS. Given the current paucity of detailed information on SoCs in textile apparel, the setting of information requirements, as prescribed under ESPR, with justified exemptions and thresholds for declaration of substances, seems clearly warranted.

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33 https://afirm-group.com/wp-content/uploads/2024/04/2024_AFIRM_RSL_2024_0404_EN.pdf
34 https://mrsl.roadmaptozero.com/
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1.3 Mutual influence of product aspects and product categorization

The analysis reported in section 1.2 described the product technologies as result of the complex interaction among process techniques, business models, user behaviour and legislative frameworks in the perspective of each relevant product aspects. It was crucial to analyse product technologies in silos to better understand the complexity of the ecosystem belonging to each relevant ecodesign aspect. However, these product aspects are strictly connected to each other and influence each other. The analysis of product technologies already showed that:

- Waste generation is strictly connected to recyclability and recycled content;
- The recycled content depends on the recyclability and directly affects the physical durability whenever the recycled fibres have lower performances and are fed into the recycling process;
- Physical durability is affected by maintenance and affects the repairability;
- The use of specific chemicals and substances affects the physical durability, recycling and recycled content;
- The environmental impacts are influenced by all the other relevant product aspects.

The analysis of technologies must now find a synthesis in Task 5 and Task 6, when the environmental and economic model will describe the BC and the Design Options for each product category. In this way, the interactions among the relevant product aspects will be quantified to best find potential trade-offs to be expressed in the Design Options.

The first step of this synthesis is the adoption of product categories valid for all relevant product aspects. In the case of textile apparel, this exercise is very simple because the only product aspect described via categories was the physical durability. This allows the adoption of the categories reported in **Table 5** of section 1.2.1.4 as the product categorization to be used in the following steps of the development of the PS.

Therefore, Task 5 will analyse 11 representative products, one for each product category: (1) Trousers, shorts and skirts excluding denim, (2) Denim trousers, shorts and skirts, (3) Sweaters, mid-layers and knitted dresses, (4) T-shirts and polo, (5) Shirts, (6) Blouses and woven dresses, (7) Jackets and coats, (8) Hosiery: leggings, stockings, tights and socks, (9) Underwear: underpants and boxers, (10) Swimwear, (11) Accessories.

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2 Annex

2.1 Supporting information on relevant aspects

2.1.1 Definitions of product aspects in ESPR

Table 15 reports the definitions of the 16 product aspects. The hierarchy applied for selecting the most appropriate source for each definition was the following: the current legislation, standards and scientific literature. In some cases, the authors have adapted the definition from those sources.

Table 15. Definition of product aspects

Product aspect	Definition	Source
Durability	The ability of a product to maintain over time its function and performance under specified conditions of use, maintenance and repair.	ESPR
Reliability	The probability that a product functions as required under given conditions for a given duration without an occurrence which results in a primary or secondary function of the product no longer being performed	ESPR
Reusability	Ability of a product or component that is not waste to be used again for the same purpose for which it was conceived.	JRC (adapted based on Directive 2008/98/EC definition for *'Re-use'*)
Upgradability	Ability of a product to be accessible for implementing actions to enhance its functionality, performance, capacity, safety or aesthetics.	JRC (adapted based on ESPR definition for *'Upgrading'*)
Repairability	Ability of a defective product or waste object to return to a condition where it fulfils its intended use.	JRC (adapted based on ESPR definition for *'Repair'*)
Possibility of maintenance	Ability of a product to be kept in a condition where it is able to fulfil its intended purpose through one or more actions.	JRC (adapted based on ESPR definition for *'maintenance'*)
Possibility of refurbishment	Ability of a product or a discarded product to be prepared, cleaned, tested, serviced and, where necessary repaired to restore its performance or functionality within the intended use and range of performance originally conceived at the design stage at the time of the placing of the product on the market.	JRC (adapted based on ESPR definition for *'refurbishment'*)
Presence of substances of concern	The presence of substances that: - meet the criteria laid down in Article 57 of Regulation (EC) No 1907/2006 and are identified in accordance with Article 59(1) of that Regulation - are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in one of the hazard classes or hazard categories listed under Article 2(27)(b) of ESPR - are regulated under Regulation (EU) 2019/1021; or - negatively affect the reuse and recycling of materials in the product in which they are present	ESPR
Energy use and energy efficiency	<u>Energy use:</u> Use of energy in all lifecycle stages of a product <u>Energy efficiency</u>: the ratio of output of performance, service, goods or energy to input of energy.	JRC JRC
Water use and water efficiency	<u>Water use:</u> Use of water in all lifecycle stages. <u>Water efficiency</u>: The ratio of output of performance, service, goods to input of water.	JRC JRC

Product aspect	Definition	Source
Resource use and resource efficiency	<u>Resource use:</u> Use of raw materials, mainly abiotic (minerals, metals, fossil fuels), in all lifecycle stages. It can also include other biotic resources such as land, air, ecosystems. The use of natural resources can be accounted for as the volumes of resources consumed (materials) or used (land, air, ecosystems), or the impacts derived from the use of resources. Water and energy are not considered within resources under the scope of ESPR. <u>Resource efficiency:</u> The ratio of output of performance, service, goods to input of resources, raw materials, air, land, soil and ecosystem services.	JRC and (BIO Intelligence Service, DG for Enterprise and Industry (EC), 2013)
Recycled content	Proportion, by mass, of recycled material, from pre- and post-consumer waste, in a product or packaging.	ISO 14021
Possibility of remanufacturing	Possibility of producing through actions a new product from objects that are waste, products or components and through which at least one change is made that may affect the performance, purpose or type of the product.	JRC (adapted based on ESPR definition for *'Remanufacturing'*)
Recyclability	Ability of products after becoming waste to be reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.	JRC (adapted based on Directive 2008/98/EC definition for *'recycling'*)
Possibility of recovery of materials	Ability of products after becoming waste to be recovered through any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling.	JRC (adapted based on Directive 2008/98/EC definition for *'material recovery'*)
Environmental impacts	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from a product during its life cycle	ESPR
Expected generation of waste	Generation of any substance, or object that the holder discards or intends or is required to discard.	JRC (adapted based on Directive 2008/98/EC definition for *'waste'*

Source: own elaboration

2.1.2 Qualitative assessment based on technical, socioeconomic and environmental dimensions

In this section, a qualitative assessment is carried out, focusing on three dimensions, with information collected via literature review. Only those aspects that are considered relevant after the assessment based on key guiding questions are evaluated (therefore, every aspect except 'possibility of recovery of materials' is evaluated in this section).

2.1.2.1 Durability

Durability is the ability of a product to maintain over time its function and performance under specified conditions of use, maintenance and repair. In the context of textile apparel, durability can be classified as intrinsic and extrinsic (emotional).

Intrinsic durability refers to physical and measurable characteristics of products, such as fabric strength, abrasion resistance, pilling, wrinkling, colour fastness, dimensional changes, seam slippage, etc. Intrinsic durability is often related with product quality, as described in Piippo et al., (2022).

Quality is a fundamental aspect of the durability and usability of clothing, and thus plays a role on its lifespan (Aakko and Niinimäki, 2021). Extrinsic durability refers to subjective and perception aspects of products, such as emotional attachment by users. This section focuses only on the intrinsic durability of textile apparel because it best corresponds to the durability definition provided by the ESPR.

<u>Characteristics of the products in the scope</u>

Durability is directly related with product lifespan. It must be noted that the lifetimes of textile apparel are, to a degree, subjective (Cooper and Claxton, 2022). In fact, there is no common approach to assess or guarantee the physical durability of textile apparel; nor are there legislative standards that apply directly to textile apparel, other than the general requirement under consumer legislation that goods are 'fit for purpose' (Cooper and Claxton, 2022).

Literature review suggests that there is room for improvement in the average durability of textile apparel. In the current market, many products are well made and have lifetimes that would generally be considered satisfactory. However, the lifetime of many other products is unduly short due to inadequate performance, in part due to pressure to meet predetermined price points (Cooper and Claxton, 2022). It is possible to influence the intrinsic durability of products with many factors, which include the use of different fibres: for instance, in the manufacturing of denim products, the utilization of synthetic fibres, linen and hemp -rather than 100% cotton- can help to produce high-durability denim products particularly with respect to tensile and abrasion resistance (Elmogahzy, 2020).

The most common physical failures in textile apparel are related to colour fading (particularly for jersey and woven fabrics) and pilling of knitwear and jersey items. Fabric breakdown (fraying or thinning around the hems) and wear round the crotch of trousers and jeans, and accidental damage due to stains, tears and rips, are also common. Other failures include loss of dimensional stability, logo failure, discolouration, holes in seams and trim failure (Cooper and Claxton, 2022). Even though they are not the main cause for physical failures, priority parts such as zippers, buttons, etc., may also have a relevance in product durability.

<u>Environmental</u>

Extending the lifetime of textile apparel has been highlighted as the most effective method of reducing the impact of the industry on the environment. For instance, extending the average life of clothes by 3 months' usage per item could reduce carbon, water and waste footprints by 5-10% (Goworek et al., 2020). Extending the average life of clothes by nine months of active use per item would typically lead to a reduction in the carbon, water and waste footprints of 27%, 33% and 22%, respectively (Cooper and Claxton, 2022).

Moreover, almost all life-cycle stages of textile apparel entail significant energy consumption (as described in section 3.3.2 of the 1st milestone). Some processes, such as the extraction of raw materials or production processes -such as spinning, knitting and weaving- are highly energy demanding. The longer the products are in active use by consumers (the more durable the products), the more likely it is to offset the manufacturing of new products, thus reducing the industry's impacts related to energy.

<u>Socioeconomic</u>

Durability in the context of textile apparel collides with one of the prevalent business models, based on fast trend turnovers and short production times. This business model does not offer space for developments to improve durability of products, as it focuses on short times between design and product availability, and aims to low pricing obtained with production of large volumes manufactured in specific locations and conditions (Dan and Ostergaard, 2021). Therefore, an increase in the durability of products may affect negatively manufacturers whose strategy is based on such business models, since the prevailing commercial drive is to save costs (Goworek et al., 2020); whereas it could affect positively manufacturers which are already focusing on the durability of products.

An increase in the durability of textile apparel could stimulate the establishment of other product-related businesses. Increasing textile apparel durability could be supported by an increase in the number of companies providing clothing repair services. Moreover, products with enhanced durability seem a necessary condition for the existence of businesses based on product renting or sharing. These businesses could extend the use of products and potentially reduce the purchase of new items if they do not incentivise overconsumption.

It is worth noting where the socioeconomic changes of product durability would be perceived. Whereas any changes in product manufacturing would mostly take place outside the EU (which is where most manufacturing takes place today) (section 5.1 of the 1st milestone), the effects related with repair, renting and sharing services would be experienced within the EU.

Consumers are increasingly interested in textile products with enhanced durability: around 90% of consumers think that apparel should be made to last longer (European Commission, 2019). There are consumers in different age groups and markets who consider durability, in connection with quality, when making fashion purchases, even if sustainability is not their main motivation (Goworek et al., 2020).

Durability has been highlighted as one of the top three aspects to influence the decision to purchase apparel such as coats or jackets (Consumers, Health, Agriculture and Food Executive Agency. et al., 2018). Around 43%

of consumers in some Member States express a willingness to buy long-lasting apparel despite the price (AK Wienn and Greenpeace, 2023).

It is also worth noting that design for physical durability involves the development and testing of yarns, fabrics and textile apparel to meet specified performance standards that can withstand prolonged wear (Claxton and Kent, 2020), which could have an effect on product purchase price.

Qualitative assessment of relevance

Based on the above, durability is considered a relevant product aspect in the context of textile apparel.

2.1.2.2 Reliability

Reliability is the probability that a product functions as required under given conditions for a given duration without an occurrence which results in a primary or secondary function of the product no longer being performed.

In the context of textile apparel, reliability can be understood as the ability of a product to retain the physical characteristics that allow its use. Therefore, reliability is directly linked with the intrinsic durability of products. Ensuring that textile apparel are durable inherently makes them more reliable. Reliability of textile apparel can be interpreted as the ability of a product to avoid or delay damages related with colour fading, discolouring, pilling, wear and tear, dimensional stability or seam defects, among others.

Characteristics of the products in the scope

Most of the rationale provided for durability in section 2.1.2.1 is applicable for reliability. There is room for improvement in the reliability of textile apparel: many products in the market have lifetimes that would generally be considered satisfactory, whereas in other products, lifetime is unduly short due to inadequate performance. The choice of fibres and the way they are processed can have an influence on the reliability of products: for instance, in the manufacturing of denim products, the utilization of synthetic fibres, linen and hemp -rather than 100% cotton- can help to produce denim products with higher tensile and abrasion resistance (Elmogahzy, 2020). It must be noted that, on occasions this can affect negatively the recyclability of the product. As in the case of durability, even though priority parts are not the main cause for physical failures, they may also have a relevance in product reliability.

Environment

Enhancing the reliability of textile apparel can contribute to lifetime extension. Textile lifespan extension is essential to avoid virgin natural resources withdrawals, either energy or material technologies (Amicarelli et al., 2022). Moreover, it can be concluded that the longer the products are in active use by consumers, the more likely it is to offset the manufacturing of new products, thus reducing the industry's impacts related to energy.

Socioeconomic

Reliability in the context of textile apparel is not aligned with business models based on fast trend turnovers and short production times. As a textile apparel manufacturer expressed it in (Goworek et al., 2020), "product longevity loses sales". Therefore, enhancing the reliability of products may affect negatively those manufacturers whose strategy is based on fast trend turnovers and short production times; whereas it could affect positively manufacturers which are already focusing on the reliability of products.

An increase in the durability of textile apparel could stimulate the establishment of other product-related businesses. For instance, products with enhanced reliability seem one of the necessary conditions for the existence of businesses based on product renting or sharing (a more reliable product is more likely to withstand the more intensive use within such business models). Quality considered as durability is a crucial aspect of textile apparel in the second hand markets, which enable extending the textile apparel use times after the initial user (Aakko and Niinimäki, 2021).

As in the case of durability, whereas any changes in product manufacturing to enhance the reliability of products would mostly take place outside the EU (section 5.1 of the 1st milestone), the effects related with renting and sharing services would be experienced within the EU.

Most of the rationale provided for durability in section 2.1.2.1 is applicable for reliability. Around 90% of consumers think that apparel should be made to last longer (European Commission, 2019), therefore would be interested in more reliable products.

Qualitative assessment of relevance

Based on the above, reliability is considered a relevant product aspect in the context of textile apparel.

2.1.2.3 Reusability

Reusability is the ability of a product or component that is not waste to be used again for the same purpose for which it was conceived.

In the context of textile apparel, reusability can have different interpretations. For instance, it can refer to extending the lifetime of products (for instance via repair) so that the same owner can continue using the product. It can also refer to transferring products to a new owner via donating to charity or second hand shops, renting, inheriting, trading, swapping and borrowing (Shirvanimoghaddam et al., 2020).

Characteristics of the products in the scope

Reusability and durability are also intertwined (as it happened between reliability and durability). Enhancing the performance of textile apparel increases durability, and thus enables increased use times (Aakko and Niinimäki, 2021).

There is a great potential to further increase reuse, as clothing items typically are disposed of long before the end of their technical service life (Sandin and Peters, 2018). Many products in the market have lifetimes that would generally be considered satisfactory, whereas in other products, lifetime is unduly short due to inadequate performances. As stated for reliability, the choice of fibres and the way they are processed can have an influence on the reusability of products: textile apparel with higher tensile and abrasion resistance are more likely to be reused. As in the case of durability, even though priority parts are not the main cause for physical failures, they may also have a relevance in product reusability.

An aspect related with textile product reusability is the discrepancy between technical lifetime (how long the product is designed to last) and average real use time by consumers. In section 5.8 of the 1st milestone, it has been highlighted that textile products nowadays remain in use for shorter periods, with an ever decreasing trend (some authors estimate that t-shirts are used for an average of 22 days in total). It appears that many textile products are currently underused during their initial lifetime, it can be expected that reusability strategies can counteract the negative effects of this product underuse.

Environment

Enhancing the reusability of textile apparel can contribute to lifetime extension, which is essential to avoid virgin natural resources withdrawals (Amicarelli et al., 2022). Moreover, it can be concluded that the longer the products are in active use by consumers, the more likely it is to offset the manufacturing of new products, thus reducing the industry's impacts related with energy. If the average life of textile apparel is extended by 3 years (for instance, via reuse), the carbon and water footprint and waste generation can be reduced by 5-10% (Shirvanimoghaddam et al., 2020).

Socioeconomic

Reusability in the context of textile apparel is also in opposition with business models based on fast trend turnovers and short production times. Therefore, enhancing the reusability of products may affect negatively those manufacturers whose strategy is based on such business models; whereas it could affect positively manufacturers which are already focusing on the reusability of products (some companies claim that their products are not designed or made for use by only one user, but many users (Piippo et al., 2022).

Textile apparel reuse has been related with collaborative consumption. Increase product reuse could boost product-service systems, commercial sharing systems and access-based consumption (Shirvanimoghaddam et al., 2020). These business models can contribute to intensifying their use and reducing the purchase of new items. In this context, the relationship between performances and durability arises again: high technical performance enables textile apparel to be used for a longer time and enables further uses through, for example, renting, leasing and second-hand markets (Piippo et al., 2022). However, it must be noted that, although reuse of textile apparel takes place today, supply exceeds demand and many wearable items end up either exported (Cooper and Claxton, 2022) or in landfills (Gowprek et al., 2020).

Reusability can also be associated with take-back services and second-hand shops. In such schemes, companies maintain and sell the products again, enabling a new life for the product with a new consumer (Piippo et al., 2022).

For some consumers, buying high-quality second-hand clothes (in other words, reusing textile apparel) represents ethical consumption, since it enables prolonging the lifespan of existing products and avoiding the traditional fashion production chain (Aakko and Niinimäki, 2021). Moreover, in section 6.2.5 of the 1st milestone it has been mentioned that second-hand textile apparel are experiencing fast growth. Around 37% of the population actively engages in buying second-hand apparel (D&B, 2020). It must be noted, however, that reusability does not change overconsumption and overproduction patterns.

Qualitative assessment of relevance

Based on the above, reusability is considered a relevant product aspect in the context of textile apparel.

2.1.2.4 Upgradability

Upgradability is the ability of a product to be accessible for implementing actions to enhance its functionality, performance, capacity, safety or aesthetics of a product.

In the context of textile apparel, upgradability can also be considered a factor that contributes to the overall durability of a product. An item of textile apparel that is upgradeable will have more chances to extend its lifetime, and therefore be more durable.

Characteristics of the products in the scope

An upgradable item of textile apparel may be one with modular components –such as detachable or interchangeable parts- that allow for updates and style changes without replacing the entire item. Although some upgradable products and designs may exist today, these type of modular designs are innovative, but not yet part of the mainstream market. Despite this lower relevance in the market today, upgradability is one of the possible strategies that can contribute to product lifetime extension. Upgradability is mostly associated with products made of physically durable fabrics.

Environment

Possibly due to the lower relevance in the market today, the authors have not found any study that highlights the potential environmental benefits of increasing the upgradability of textile products. In any case, if it is assumed that upgradability can contribute to extend the lifetime of textile apparel, it could also be concluded that upgrading products may have environmental benefits similar to the ones reported in section 2.1.2.1 on durability.

Socioeconomic

Although upgradable textile products can still be considered to be a niche in the market today, it can be concluded that they are also in opposition to business models based on fast trend turnovers and short production times. Modular products that can be upgraded will last longer and therefore prevent the sales of new products. Therefore, promoting the upgradability of products may affect negatively those manufacturers whose strategy is based on such business models; whereas it could affect positively manufacturers which focus on their upgradability.

There is currently no evidence that suggests that increasing the upgradability of products may stimulate the creation of alternative business models based on renting or sharing. It could contribute to the creation of jobs on the clothing repair sector, which could undertake some of the activities related with product upgrade that cannot be carried out by consumers (replacing older by upgraded modules, for instance).

Possibly due to the lower relevance in the market today, the authors have not found any evidence on the willingness of consumers to purchase upgradable textile products. The price to upgrade a product, compared with the price of a new product, may also be a factor for the willingness of consumers to upgrade textile apparel.

Qualitative assessment of relevance

Based on the above, upgradability is considered a relevant product aspect in the context of textile apparel.

2.1.2.5 Repairability

Repairability is the ability of a defective product or waste object to return to a condition where it fulfils its intended use. In the context of textile apparel, repairability is directly linked with durability. One of the factors that makes a product more durable is its potential to be repaired. Repair makes it possible to increase product lifespans as well as value creation (Laitala and Klepp, 2021). Either as an activity carried out by the consumer or as a service provided by a company, repair is another way in which to extend use-time of textile apparel (Piippo et al., 2022).

Characteristics of the products in the scope

The repairability of textile apparel can be influenced at the design stage, for instance, considering their ease of disassembly, ensuring that products can be taken apart to replace worn or damaged components (Cooper and Claxton, 2022).

The presence of priority parts has been mentioned in previous sections on durability and reliability. Priority parts are particularly relevant for repairability, since these are the components with the highest frequency of failure and functional relevance. In the case of textile apparel, a possible list of priority parts (non-exhaustive) comprises fabrics, zips, buttons and embellishments such as sequins, gems and beads. It is worth noting that relatively few pieces of textile apparel with these components have failures, which suggests that the relevance of repairability is lower than, for instance, the relevance of reliability. Missing buttons and broken zips are the main problems, followed by missing embellishments (Cooper and Claxton, 2022).

Environment

Repair of textile apparel has environmental benefits. As highlighted in (Luo et al., 2023), the frequent use of a product will cause wear and tear and shorten its service life, while the repair process will extend the service life of the product and consequently reduce the purchase of new products and excessive waste of resources. It must be noted that providing spare parts for repairability increases the environmental impact of the product, if such parts are finally not used.

Socioeconomic

Currently, the professional services used for repair of clothing are companies mostly independent of the production and sales of clothes (Laitala and Klepp, 2021). A rise in the availability of more reparable clothing could stimulate the creation of business related with clothing repair.

Repair could also be stimulated by the same product manufacturers, either providing clothing repair as a service, or providing information to consumers on how to carry out simple repairs. Some brands offer more service-oriented solutions, such as repair and alterations, while others are designing modular or more adaptable clothing (Goworek et al., 2020).

In fact, the number of repairs conducted privately is at least three times more frequent than professional repairs, since minor mending of textiles often only requires needle and thread, a limited amount of time and only rather basic skills (Laitala and Klepp, 2021).

Repair of clothing carried out by consumers is diminishing, due to the current low skills of consumers, influenced by the scarcity of available time to carry out repairs, the lack of appropriate equipment and price (Finnish Ministry of the Environment, 2023). Therefore, only 11% of consumers consider repairability to be important when purchasing apparel items such as coats and jackets (Consumers, Health, Agriculture and Food Executive Agency. et al., 2018).

The price of repair is a fundamental factor in the case of textile apparel. The price of repairing clothes depends a lot on the type of textile apparel and repair needed. A general trend observed is that consumers are not willing to pay much for the repair of textile apparel, and especially not for low-priced textile apparel. Consumers compare the price to a new textile apparel, which often is the same or even lower than repair or adjustments done by the tailor (Laitala and Klepp, 2021). The authors have not found specific data regarding the willingness of consumers to pay for the repair of textile apparel. Using as a reference values from other product groups, the willingness to pay for repairs of small electronics is between 20% and 40% of the replacement cost (Cordella, Sanfelix, et al., 2019; Svensson-Hoglund et al., 2021).

In essence, clothes would be worn longer if repair services were cheaper (or products more expensive): 27% of consumers agree that they would wear their textile apparel longer if they were better at repairing them (Laitala and Klepp, 2021). For those few consumers that do carry out repairs, it is worth noting that textile apparel has a much higher share of successful repairs than other products such as electrical appliances.

Qualitative assessment of relevance

Based on the above, repairability is considered a relevant product aspect in the context of textile apparel.

2.1.2.6 Possibility of maintenance

The possibility of maintenance is the ability of a product to be kept in a condition where it is able to fulfil its intended purpose through one or more actions. In the context of textile apparel, it consists of the set of activities that a consumer carries out, fundamentally during the use phase of the product, in order to maintain it in a condition that satisfies all their needs associated to the product. This can include activities such as washing, drying, ironing, folding, storing, wearing in specific environments and conditions, etc.

Characteristics of the products in the scope

Washing is potentially the most relevant maintenance activity for textile apparel, which are prone to getting dirty or soiled. The ability to remove dirt and stains can be influenced by design, for instance by the choice of materials. Inherent fibre properties affect the soiling characteristics of textile apparel. Cotton gets dirty easily, but can be washed efficiently and thus cleaned. In contrast, wool resists staining and develops less odour, but stains are difficult to remove (Laitala and Klepp, 2018). Similar trade-offs can be expected for other maintenance activities such as drying or ironing.

Environment

Textile apparel maintenance activities, because they are repeated often and by all people in the world, constitutes a significant environmental impact. Washing, drying and wrinkle removal are repeated on a regular basis. The longer an item of textile apparel is used, the more important this phase will be for the overall environmental impact of the textile apparel (Laitala and Klepp, 2018).

Maintenance can contribute to extend the lifetime of products and therefore reduce their environmental impact. It is important for keeping products in use and for motivating consumers to repair them when needed (Laitala and Klepp, 2021). Extending textile apparel lifetimes should also take into account how more durable textile apparel items can be cared for sustainably by consumers, for example by avoiding dry-clean only fabrics (Goworek et al., 2020).

Socioeconomic

Manufacturers of textile apparel emphasize that optimal care and maintenance is a significant factor for extending product life. For them, it is important to determine which products customers need, but also how they use and care for these products. Since it is often the customers who care for the products, it is important for companies to share information on correct maintenance (Piippo et al., 2022).

The possibility of maintenance can also be a factor in take-back services. In such schemes, companies maintain the products they sold, in order to sell them again, enabling a new life for the product with a new consumer (Piippo et al., 2022).

Similarly to previous product aspects, the possibility of maintenance is in opposition with business models based on fast trend turnovers and short production times. A product which is easier to be maintained will delay the sale of new products, delaying their replacement. Therefore, promoting the possibility of maintenance of products may affect negatively those manufacturers whose strategy is based on such business models; whereas it could affect positively manufacturers which focus on product maintenance.

Maintenance of textile products relies mostly on users. Most of the laundering and storing of textiles is carried out by the owner of the apparel. Manufacturers already provide maintenance instructions to users on how to wash and take care of textile products, on a voluntary basis. As pointed out in section 6.3.2 of the 1st milestone, a significant percentage of users follow these care instructions, but the adherence diminishes after the initial wash.

Qualitative assessment of relevance

Based on the above, possibility of maintenance is considered a relevant product aspect in the context of textile apparel.

2.1.2.7 Possibility of refurbishment

The possibility of refurbishment is the ability of a product or a discarded product to be prepared, cleaned, tested, serviced and, where necessary repaired to restore its performance or functionality within the intended use and range of performance originally conceived at the design stage at the time of the placing of the product on the market. In the context of textile apparel, it can be interpreted as a very similar –or equivalent- aspect to repairability. In essence, when a product is repaired, it may also follow the steps described in the definition of possibility of refurbishment (preparing, cleaning, testing, servicing and repairing). As in the case of repair, the possibility of refurbishing is directly linked with durability.

Characteristics of the products in the scope

As in the case of repairability, the possibility of refurbishing of textile apparel can be influenced at the design stage, for instance, considering their ease of disassembly, ensuring that products can be taken apart to replace worn or damaged components (Claxton and Kent, 2020). The presence of priority parts has been mentioned in previous sections on durability, reliability and repairability. Priority parts are also particularly relevant for the possibility of refurbishing, since these are the components with the highest frequency of failure and functional relevance, and therefore the parts which more likely may need to be substituted in a potential refurbishing activity. Refurbishment is strictly connected to the physical durability of priority parts and the price related to refurbish a used product or waste rather than manufacturing a new one.

Environment

Possibly due to the similarities with product repair, the authors have not found scientific literature highlighting the potential environmental benefits of textile apparel refurbishing.

Socioeconomic

Similarly to the case of previous product aspects, the possibility of refurbishment is in contrast with the business models based on fast trend turnovers and short production times. A product that can be refurbished will reduce the opportunity of selling new items. Therefore, promoting the possibility of maintenance and refurbishment of products may affect negatively those manufacturers whose strategy is based on such business models; whereas it could affect positively manufacturers which focus on product maintenance and refurbishment.

A rise in the availability of products which are easier to be refurbished could stimulate the creation of business related with textile apparel repair.

Qualitative assessment of relevance

Based on the above, possibility of refurbishment is considered a relevant product aspect in the context of textile apparel.

2.1.2.8 Presence of substances of concern

The presence of substances of concern should be understood as the existence of chemicals in products that for reasons of their intrinsic hazards pose risks to human health or the environment, or that otherwise negatively affects the reuse and recycling of materials in the product in which they are present. This may bring about the need to consider regulatory action, improved management and/or substitution with safer alternatives, whenever feasible. ESPR specifically requires to track the presence of these substances in products.

In ESPR, a substance of concern means a substance that:

(a) meets the criteria laid down in Article 57 of Regulation (EC) No 1907/2006 and is identified in accordance with Article 59(1) of that Regulation;

(b) is classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in one of the following hazard classes or hazard categories:

(i) carcinogenicity categories 1 and 2;

(ii) germ cell mutagenicity categories 1 and 2;

(iii) reproductive toxicity categories 1 and 2;

(iv) endocrine disruption for human health categories 1 and 2;

(v) endocrine disruption for the environment categories 1 and 2;

(vi) persistent, mobile and toxic or very persistent, very mobile properties;

(vii) persistent, bioaccumulative and toxic or very persistent, very bioaccumulative properties;

(viii) respiratory sensitisation category 1;

(ix) skin sensitisation category 1;

(x) hazardous to the aquatic environment — categories chronic 1 to 4;

(xi) hazardous to the ozone layer;

(xii) specific target organ toxicity — repeated exposure categories 1 and 2;

(xiii) specific target organ toxicity — single exposure categories 1 and 2;

(c) is regulated under Regulation (EU) 2019/1021; or

(d) negatively affects the reuse and recycling of materials in the product in which it is present;

Characteristics of the products in the scope

As already pointed out in section 3.3.2 of the 1st milestone, the raw materials extraction and manufacturing of textile apparel involve the use of a wide variety of chemical substances and mixtures, which includes pesticides, solvents, surfactants, dyes, pigments, stain repellents, flame retardants or biocides, among others, as well as water. The demand of chemical compounds by the textile industry is estimated to use around 25% of global chemical production (Raj et al., 2022). Many of the chemicals used during textile manufacturing are associated with spinning and weaving and wet processing. A single European textile-finishing company uses over 466 g of chemicals per 1 kg of textile (Niinimäki et al., 2020).

Chemicals are used in the manufacturing of textile apparel with a specific purpose, such as providing a certain level of resistance to abrasion, adding colour, waterproofing, etc. The presence of substances of concern can be influenced at the design stage, via substitutions by safer alternatives (often with trade-offs) (Zhang and Hale, 2022).

Environment

Chemicals have an influence in almost all lifecycle stages of a textile product. Chemicals used during manufacturing are often discharged or results in releases and get in direct contact with soil and water bodies. Consumers are directly exposed to chemicals in the textile during the use phase. Chemicals may also have an influence at end-of-life, either hindering processes such as recycling or being released to the environment if apparel is landfilled or incinerated.

Eliminating or reducing the presence of substances of concern has been highlighted as one of the key areas with potential of improvement regarding ecodesign (Ellen MacArthur Foundation, 2017; Bauer et al., 2018; Niinimäki et al., 2020). For instance, natural cotton fabric dyeing using dyes of plant origin (white onion) can reduce the impacts on human health and ecosystems (Amicarelli et al., 2022).

Socioeconomic

Companies in the textile apparel sector aim to reduce production costs through manufacturing in locations with lower production costs and where often environmental regulation is laxer or pollution-mitigating technologies are not legally required. This approach to manufacturing often leads not only to high environmental impacts from use of chemicals but increased health risks for factory workers, cotton farmers and fashion consumers (Niinimäki et al., 2020).

Despite being in direct contact with chemicals when wearing apparel, 60% of respondents to a survey in the EU perceived chemicals in apparel fabrics as representing a minimal risk (European Commission, 2019).

Qualitative assessment of relevance

Based on the above, presence of substances of concern is considered a relevant product aspect in the context of textile apparel.

2.1.2.9 Energy use and energy efficiency

Energy use can be defined as the total use of energy in all lifecycle stages of a product. Energy efficiency is the ratio of output of performance, service, goods or energy to input of energy.

Characteristics of the products in the scope

Almost all life-cycle stages of apparel have significant energy consumption, particularly the extraction of fibres such as silk; production processes such as spinning, knitting and weaving; or thermal treatments during production (see section 3.3.1 of the 1st milestone). Although manufacturing covers about 70-80% of total lifecycle energy consumption (Sandin et al., 2019; Quantis, 2021), energy is also consumed in the use phase for laundering, ironing and drying.

There is a wide range of materials available for manufacturers, with different performance in terms of energy use and energy efficiency. Considering the manufacturing stage, some fibres are less energy intensive than others. However, reductions in energy use may come with trade-offs in other properties of the fibre (Niinimäki et al., 2020).

Considering the use phase, the electricity consumed during domestic washing amounts to 2% of household usage, while tumble drying accounts for 4.5% (Zhang et al., 2022). There are also examples of energy efficiency improvement potential areas in the use phase, described in (Zhang et al., 2022). For instance, products made from hygroscopic fibres require higher energy in tumble drying than their hydrophobic fast-drying synthetic counterparts (Zhang et al., 2022). Reductions in the number of launderings can also be achieved by manufacturing clothes with odour reduction thanks to fabrics enabled with silver, which has antimicrobial properties (Amicarelli et al., 2022). Some fibres require lower temperatures for laundering than others (less energy use). Some materials require ironing to achieve a minimum aesthetic performance, whereas others do not need to be ironed. However, different fibres will provide different performance and aesthetics. Design strategies tend to be aimed at reducing rather than eliminating the negative impacts of the use phase, typically in the design of clothes for less frequent washing and use of lower laundering temperatures to prolong textile apparel life (Claxton and Kent, 2020)

There is room for improvement in the energy efficiency of textiles manufacturing as well. In (Zhang et al., 2022), several examples are provided: low-twist spinning technology introduces false twisters between the front roller and the yarn guide, and can achieve a twist reduction of 20-40%; significant energy saving in air humidification can be achieved by using energy-efficient nozzles and variable-frequency drives based on the real-time humidity conditions in the spinning and weaving process; or high-volume, low-pressure nozzles can save up to 26% of energy thanks to their optimized nozzle geometry (Zhang et al., 2022). In the case of denim apparel, the industry is transitioning from stonewashed denim to more energy-efficient methods such as enzyme treatment, mechanical abrasion, ozone fading, water jet fading and laser treatment (Elmogahzy, 2020). It is worth noting that, in the context of the Industrial Emissions Directive, the Reference Document for the Textiles Industry (Roth et al., 2023) addresses energy use for installations located in the EU and points out the Best Available Techniques.

<u>Environmental</u>

As pointed out in section 5.4.3 of the 1st milestone, considering the manufacturing stage, the energy consumption in the global textile industry was estimated to be 2% of the global energy consumption. Section 3.3.1 of the 1st milestone reports that almost all stages of the textile apparel value chain are energy demanding. Indirectly related with energy, the apparel industry is reported to be responsible for about 6.5% of global GHG emissions (Niinimäki et al., 2020).

The substantial consumption of electricity in the use stage of textiles was also revealed to have a significant impact on the environment due to repeated use and care operations, in some cases even exceeding the contribution of the production stage (Luo et al., 2023).

<u>Socioeconomic</u>

As mentioned in section 5.4.3 of the 1st milestone, the cost of energy plays an important role in the textile industry. In fact, the increase of the cost of energy in the EU in 2022 negatively affected the EU textile production. Moreover, the national energy strategies influence the establishment of textile industry focussing on specific stages of the value chain.

Textile apparel are generally not perceived by consumers as energy-related products. Possibly because of that, the authors have not found any evidence on the willingness of consumers to purchase energy efficient textile products.

Users can have an influence on the energy consumed during the lifecycle of apparel, mostly in the laundering, ironing and drying activities. Following the instructions available in labelling in terms of water temperature can help to reduce energy consumption. Reducing the frequency of ironing may also save energy. Substituting the use of tumble driers by air-drying (when possible) can also have a positive effect.

<u>Qualitative assessment of relevance</u>

Based on the above, energy use and energy efficiency is considered a relevant product aspect in the context of textile apparel.

2.1.2.10 Water use and water efficiency

Water use is the use of water in all lifecycle stages of a product. Water efficiency is the ratio of output of performance, service, goods to input of water.

<u>Characteristics of the products in the scope</u>

Apparel manufacturing requires enormous volumes of water in fabric production (Jia et al., 2020). Typically, 70-250 l of water are used for every kilogram of finished textiles (Zhang et al., 2022). Water is also consumed during the use phase in laundering activities.

There is a wide range of materials available for manufacturers, with different performance in terms of water use and water efficiency. Cotton and hemp are the most water-demanding among textile fibres, whereas polyester and polypropylene need the least amount of water. However, reductions in water use may come with trade-offs in other properties of the fibre (Niinimäki et al., 2020).

There is room for improvement in the water efficiency of textiles manufacturing. In (Zhang et al., 2022), several examples are provided: a foam-laying technique has been studied as a replacement for the wet-laying non-woven process, using 20% of the water and saving energy simultaneously; for synthetic fibres, colourless polymers can be structurally coloured with nano-sized pigment inclusions via spin dyeing, achieving 50% water savings; recycling wastewater generated from spent dyeing and rinsing baths through catalytic ozonation with carbon aerogel is a method to minimize water consumption.

There are also examples of water efficiency improvement potential areas in the use phase (for laundering), described in (Zhang et al., 2022). For instance, products made from hygroscopic fibres require more water than their hydrophobic fast-drying synthetic counterparts. It is worth noting that, in the context of the Industrial Emissions Directive, the Reference Document for the Textiles Industry (Roth et al., 2023) addresses water use for installations located in the EU and points out the Best Available Techniques.

Environmental

Considering the initial stages of textile apparel production, water consumption for materials extraction and manufacturing is estimated to account for 4% of global freshwater extraction (Ellen MacArthur Foundation, 2017). Just cotton is estimated to account for 2.5% of water consumed globally every year (Amicarelli et al., 2022). In the EU, the production of textile apparel, footwear and household textiles purchased in 2020 was around 4 000 million m^3 of blue water ([42]).

Considering the use stage of textile apparel, the substantial consumption of water in the use stage of textiles was revealed to have a significant impact on the environment due to repeated use and care operations, in some cases even exceeding the contribution of the production stage (Luo et al., 2023).

Socioeconomic

As described in section 5.7 of the 1st milestone, the global value chain of textile apparel causes most of its environmental impacts in the production stages, and most of these stages occur outside of the EU. In particular, in countries that allow production at lower costs (due to poor labour conditions and less stringent measures on environmental protection). This is particularly relevant for water consumption, an aspect which is directly related with the specific location. For instance, cotton has the highest water footprint of any fashion fibre (Niinimäki et al., 2020). For making a cotton t-shirt, 2 700 litres of water are used (Shirvanimoghaddam et al., 2020).

Textile apparel are generally not perceived by consumers as water-related products. Possibly because of that, the authors have not found any evidence on the willingness of consumers to purchase water efficient textile products. However, water is also consumed during the use phase in laundering activities, which are mostly influenced by the users. As highlighted in previous sections, different washing habits are observed across countries, with factors such as age and societal norms also having an influence. User perceptions about hygiene and convenience may impact washing frequency, influencing the consumption of water during the use phase. There is also a relevant interaction with laundry detergents (some of them might require more water than others to achieve the same level of cleanliness).

Qualitative assessment of relevance

Based on the above, water use and water efficiency is considered a relevant product aspect in the context of textile apparel.

2.1.2.11 Resource use and resource efficiency

Resource use is the use of raw materials, mainly abiotic (minerals, metals, fossil fuels), in all lifecycle stages. It can also include biotic resources such as land, air, ecosystems. The use of natural resources can be accounted

[42] Blue water refers to fresh surface and groundwater

for as the volumes of resources consumed (materials) or used (land, air, ecosystems), or the impacts derived from the use of resources. Water and energy are not considered within resources under the scope of ESPR given these are addressed as separate product aspects. Resource efficiency is the ratio of output of performance, service, goods to input of resources, raw materials, air, land, soil and ecosystem services.

Characteristics of the products in the scope

The textile apparel industry is resource-intensive (Piippo et al., 2022). Most of these resources are consumed in the raw material extraction and manufacturing stages. This product aspect is therefore related with product parameters, reported in Annex I to ESPR, such as 'use or content of sustainable renewable materials' and 'reduction of materials consumption', among others.

Considering textile manufacturing, there are a wide variety of techniques, each of them with a different level of resource efficiency. Taking cotton as an example, it may be produced following organic farming, conventional farming or regenerative agriculture and using different quantities of land, water, chemicals and energy according to the climate and the ecosystem where it is cultivated. Each specific cultivation practice in a given location has a specific crop yield (or efficiency in the use of resources). Similarly, manmade cellulosic fibres can be produced using cellulose from recycled wood, agricultural waste, virgin wood coming from sustainably managed forests, virgin wood coming from deforestation-free forests or from unknown sources, etc. All these options use different resources and affect different ecosystems.

Resource efficiency can also be linked with the process of reducing the weight of products to improve their environmental performance. This practice, aimed at decreasing material use throughout the product lifecycle, it is also known as lightweighting. Denim fabrics, for instance, can be made in many weights. Light denim will be suitable for dresses or shirts where drape, softness and flexibility are required. Heavy denims are typically used for blue jeans trousers and skirts (Elmogahzy, 2020). Although light weights use less material, they also provide different properties to textile apparel. Heavier weight fabrics are generally more durable and less susceptible to abrasion and wear, while fabrics with a tighter, more compact construction are also more resistant to damage (Cooper and Claxton, 2022). Therefore, the authors consider that lightweighting is not a relevant product parameter for textile apparel.

Environmental

The textile industry is the fifth industrial sector for primary use of materials, mainly related to the extensive production of natural origin fibres and man-made cellulosic fibres. The estimates of textile fibre production were around 116-124 million tonnes in 2022 (Textile Exchange, 2022).

Socioeconomic

Similarly to energy efficiency and water efficiency, resource efficiency does not appear to be a relevant aspect influencing the behaviour of consumers when purchasing textile apparel.

Qualitative assessment of relevance

Based on the above, resource use and resource efficiency is considered a relevant product aspect in the context of textile apparel.

2.1.2.12 Recycled content

Recycled content is the proportion, by mass, of recycled material, from pre- and post-consumer waste, in a product or packaging. In the case of textile apparel, it is generally expressed with reference to the amount of fibres, which are at least 80% of the weight of the product.

Characteristics of the products in the scope

The possibility to use recycled material in textile apparel has been mentioned in some studies as a relevant product aspect to consider (Ellen MacArthur Foundation, 2017; Bauer et al., 2018; Niinimäki et al., 2020).

When considering the possibility of having recycled content in a product, a key aspect is the availability of recycled material in the market. In the case of textile apparel, as pointed out in section 3.3.2 of the 1st milestone, there is enough post-consumer waste from which material could be recycled and reintroduced in the manufacturing process of textile apparel. In section 5.4.1 of the 1st milestone, it has also been mentioned that a 30% increase in textile waste is expected for 2030-2035, so the supply of feedstock for recycled material seems guaranteed for the coming years.

However, when designing a product with recycled content it must be taken into account that, depending on the recycling technology, recycled fibres tend to be of lower performance than their virgin equivalents and are normally limited to single fibre content fabrics (Claxton and Kent, 2020). For instance, a maximum of 20% post-consumer mechanically recovered cotton fibres can be blended with virgin cotton before strength is compromised (Niinimäki et al., 2020).

There is room for improvement to increase the recycled content in textile apparel. For instance, chemical recycling works by breaking down fibres through a chemical dissolution process to the level of a polymer and is suitable for cellulose fibres. The process preserves fibres better than the mechanical recycling and is, therefore, anticipated to enable textile apparel to be produced with higher percentages of recycled fibres (Niinimäki et al., 2020).

Environmental

Some studies highlight that the use of recycled materials in textile apparel reduces their environmental impact. For instance, by using recycled cotton for spinning it is possible to decrease 60% of the emitted CO_2eq, reduce the consumption of oil equivalent by 11% and water by almost 80%. Similarly, the use of recycled cotton fibre has a huge potential to reduce environmental impacts, since it is possible to avoid the production of virgin cotton, with a reduction of up to 98% in water use. Substituting primary by secondary materials in a polyester jacket shows a reduction in impacts between 50%-80% in the categories of photochemical smog formation, human toxicity and water scarcity (Amicarelli et al., 2022).

Socioeconomic

Increasing the content of recycled material in textile apparel could contribute to job creation in different areas. For instance, in the collection and sorting of textiles, as well as in transport and recycling operations. The increase in recycled content might also incentivise the recycling of end-of-life waste material.

In contrast with other aspects such as durability or repairability, consumers give little importance to the use of recycled materials in apparel (11%, as highlighted in section 6.2.7 of the 1st milestone).

Qualitative assessment of relevance

Based on the above, recycled content is considered a relevant product aspect in the context of textile apparel.

2.1.2.13 Possibility of remanufacturing

The possibility of remanufacturing is the possibility of producing through actions a new product from objects that are waste, products or components and through which at least one change is made that may affect the performance, purpose or type of the product.

In the context of textile apparel, it must be noted that product attributes that make it fit for repair (such as ease of disassembly) also make it fit for remanufacturing.

Characteristics of the products in the scope

As in the case of repairability, the possibility of remanufacturing of textile apparel can be influenced in the design stage, for instance, considering their ease of disassembly, ensuring that products can be taken apart to replace worn or damaged components (Claxton and Kent, 2020).

The presence of priority parts has been mentioned in previous sections on durability, reliability, repairability and possibility of refurbishing. Priority parts are also particularly relevant for the possibility of remanufacturing, since these are the components with the highest frequency of failure and functional relevance, and therefore the parts which more likely may need to be substituted in a potential remanufacturing activity.

Environment

Possibly due to the similarities with product repair, the authors have not found scientific literature highlighting the potential environmental benefits of textile apparel remanufacturing.

Socioeconomic

Similarly with previous product aspects, the possibility of remanufacturing is in opposition with business models based on fast trend turnovers and short production times. A product which is easier to be remanufactured will reduce the opportunity of selling new items. Therefore, promoting the possibility of remanufacturing of products may affect negatively those manufacturers whose strategy is based on such business models; whereas it could affect positively manufacturers which focus on product remanufacturing.

A rise in the availability of products which are easier to be remanufactured could stimulate the creation of business related with textile apparel repair. The cost of remanufacturing may also be a significant factor for the expansion of this activity.

Qualitative assessment of relevance

Based on the above, possibility of remanufacturing is considered a relevant product aspect in the context of textile apparel.

2.1.2.14 Recyclability

Recyclability is the ability of waste materials originating from products to be reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

Characteristics of the products in the scope

It is possible to recycle textile apparel, either via mechanical, chemical or enzymatic technologies. However, due to different fibre material combinations, auxiliaries such as buttons and zippers, and various thermal treatments, fibre to fibre recycling is a complex and hardly practiced treatment (Eppinger et al., 2022). In fact, chemical and enzymatic recycling do not seem to be ready for industrial scale application, where the automatic sorting of collected textile products is crucial to effectively identifying fibre type and determining the appropriate recycling method (Zhang et al., 2022). Mechanical recycling is therefore the most common recycling technology nowadays.

Recycling may be closed loop (when materials are recycled back into the same or similar products) or open loop (when materials are converted into different types of products). In the case of textile apparel, most of the recycling processes today are open loop. As the length of the fibres and the constituent molecules are reduced by wear and laundry, fabric and fibre recycling typically yields materials of lower performances than materials made from virgin fibres (Sandin and Peters, 2018). For instance, materials recycled via mechanical recycling can be used to produce insulating materials for cars and buildings, fibre-reinforced composites and disposable non-woven products such as sanitary wipes, napkins and diapers (Zhang et al., 2022). Moreover, there are many opportunities to use cotton and textile waste for various applications including composites, microbial fuel cell, potassium-ion exchange, biochar applications, sound absorbents, thermal insulation, EMI shielding, etc. (Shirvanimoghaddam et al., 2020).

Mechanically recycled fibres generally show weakened properties (Zhang et al., 2022). This process gives the best results when the material still has some level of performance. If very poor (high wear and tear) material is mechanically recycled, up to 30-50% of virgin material needs to be added so that the performance of the material becomes sufficient (Piippo et al., 2022). This can also be observed in the case of denim products. The common approach to recycle denim products is through fabric shredding into fibres, which can be used in many applications. The success will primarily depend on the characteristics of fibres obtained from the recycling process (Elmogahzy, 2020).

There is room for improvement in the possibilities of recycling textile apparel and this may be influenced at the design stage. For instance, most apparel products currently in use are fibre blends of multiple polymers. Recycling is complicated by textile apparel being constructed of fibre blends, which require separation (Niinimäki et al., 2020). Mono-materiality in textiles has long been recognized for its great recycling efficiency without need for disassembly, making it one of the most effective design strategies for proactive material recovery and perhaps the basis for a new textile paradigm (Zhang et al., 2022).

Environmental

Some studies highlight that the use of recycled materials in textile products decreases their environmental impact (Cai and Choi, 2020; Niinimäki et al., 2020; Amicarelli et al., 2022). The environmental analysis of section 2.1.2.12 on recycled content provides some insight on the benefits of recycling textile apparel. Upcycling textile waste into new products or even recycling textile waste in another sector (e.g. as part of composite material in the automotive industry) is an important approach in a circular economy (Piippo et al., 2022).

Socioeconomic

In section 5.4.1 of the 1st milestone, a summary was provided in terms of availability of textile recycling plants. Europe, Asia and North America host 50%, 33% and 11% of global textile recycling plants, respectively. Most of these plants are able to process textile products made of many textile fibres. Increasing the recyclability in textile products could contribute to job creation in different areas: textile collection, sorting, transport and recycling.

However, at global level, only 12% of textile materials are currently recycled (Zhang et al., 2022). Only 15% of post-consumer textile waste was collected separately for recycling purposes in 2015, and less than 1% of total production was recycled in closed loop. Most of the recycled textiles were recycled into other, lower-value applications, such as insulation material, wiping cloths and mattress stuffing (Niinimäki et al., 2020).

In Solis et al (2024), the authors investigated the socioeconomic impacts of different waste management scenarios for textiles. They concluded that mechanical recycling of cotton, polyester, polycotton and polyamide achieved lower costs than incineration. However, if other recycling pathways (such as mechanical recycling of viscose, open-loop recycling, chemical recycling of cotton, polyester and polycotton) are to be competitive from the socio-economic perspective relative to incineration, technology costs need to decrease significantly.

In terms of employment, preparing for reuse and recycling create significantly more jobs than incineration and landfilling (Solis et al., 2024).

Recyclability does not seem a relevant aspect for consumers when purchasing textile apparel.

It has been mentioned above that fibre blends make the process of recycling more complex. To overcome this, mono-material apparel and footwear engineered for mechanical recycling may be manufactured from thermoplastic materials via a combination of existing machinery and processes. However, the huge variation in consumer preference is not easily satisfied by a single material (Zhang et al., 2022).

The recyclability of textile apparel can also be influenced by increasing their collection at end of life, an aspect where consumers also have an influence. Moreover, the Waste Framework Directive requires Member States to set up separate collection for textiles by 1 January 2025. It also promotes the establishment of Extended Producer Responsibility Schemes for textile products in several Member States.

<u>Qualitative assessment of relevance</u>

Based on the above, recyclability is considered a relevant product aspect in the context of textile apparel.

2.1.2.15 Environmental impacts

Environmental impacts refer to any change to the environment, whether adverse or beneficial, wholly or partially resulting from a product during its life cycle.

<u>Characteristics of the products in the scope</u>

Textile apparel include a wide variety of products, including t-shirts, shirts and blouses, sweaters, jackets, pants, dresses and accessories, among others. These products have different applications and therefore a very diverse range of performance requirements. Related with the variety of products and applications, a wide variety of possible materials and manufacturing processes arise, each one providing different characteristics to textile apparel.

This wide variety of possibilities in terms of products, materials and manufacturing processes causes that the nature of the environmental impacts is also wide. Some materials and processes might have a larger impact due to energy use and greenhouse gas emissions, whereas other have a larger impact due to water use, resource use, release of chemicals or generation of waste.

<u>Environmental aspects</u>

As highlighted in section 3.3.2 of the 1st milestone, textile apparel has relevant effects on the environment throughout its lifecycle, on different areas. For instance:

- The textile industry's water consumption is estimated to account for 4% of global freshwater extraction (Ellen MacArthur Foundation, 2017).
- In 2004, the energy consumption in the global textile industry was estimated to be equal to 2% of the global energy consumption. Additionally, the production of 1 kg of generic textile product was estimated to require about 126 MJ (about 35 kWh) of energy (Muthu, 2015).
- Numerous life-cycle stages of textile apparel involve the use of chemical substances and mixtures. Some of them are pesticides, solvents, surfactants, dyes and pigments, water and stain repellents, flame retardants, biocides and many more (Ellen MacArthur Foundation, 2017) .

- In 2019, the EU generated about 12.6 Mt of textile waste, including post-industrial, pre-consumer and post-consumer waste, representing 11%, 3% and 86% of the total, respectively.
- The European Environment Agency estimated that textile consumption in the EU in 2020 emitted 121 million tonnes of greenhouse gases. Around 75% of the emissions occurred outside Europe, specifically in Asian countries (EEA et al., 2022).
- Textile fragmentation is also a relevant aspect for the environmental impacts of textile apparel. It has been reported that one of the leading sources of microplastics pollution is the fragmentation of synthetic textiles (Boucher and Friot, 2017). Current patterns indicate that emissions of microplastics from textiles are projected to rise by approximately 22% by the year 2030 (DG ENV, 2023).
- The BREF on textiles (Roth et al., 2023) identifies and addresses the main pollutants during the manufacturing process of textile apparel, such as COD, SOx, NOx, energy consumption and water consumption.

Socioeconomic

Many of the impacts mentioned above occur outside the EU. Third countries producing textiles often have less stringent environmental and labour requirements. This allows manufacturers to reduce costs and offer final products at a lower purchase price than EU production, at the expense of environmental degradation and health issues of the workers and the communities working around the manufacturing plants. Promoting products with a lower environmental impact would contribute to the reduction of impacts across the whole value chain.

As pointed out in section 6.2.2 of the 1st milestone, most of EU consumers argue that environmental impact of products is 'very' or 'rather important' in their purchasing decisions (European Commission. Directorate General for Environment., 2023). Information is a key aspect to convey messages on the environmental performance of products: around 82% of consumers believe there is insufficient information available on environmental aspects associated with apparel (European Commission, 2019).

Qualitative assessment of relevance

Based on the above, environmental impact is considered a relevant product aspect in the context of textile apparel.

2.1.2.16 Expected generation of waste

The expected generation of waste is the generation of any substance, or object that the holder discards or intends or is required to discard.

Characteristics of the products in the scope

Waste is generated in different lifecycle stages of textile apparel. Depending on that, waste can be classified as (Huygens et al., 2023):

- Post-industrial waste: waste generated during the manufacturing of textile products and their precursors.
- Pre-consumer waste: waste generated at retail stages (e.g. unsold textiles).
- Post-consumer waste: textiles that have been disposed of after consumption and use by the citizen or end-users of commercial and industrial activities (hotel, healthcare, etc.), commonly referred to as household and commercial post-consumer textile waste, respectively.

Therefore, waste is relevant in different stages of the textile product value chain. There seems to be room for improvement in the expected generation of waste. In terms of post-industrial waste, methods have been developed to design textile apparel that minimises cutting waste and puts nearly all offcuts into production (Niinimäki et al., 2020). Most of the leftover material from textile apparel manufacturing (post-industrial waste) ends up dumped or burned (Aus et al., 2021). It is technically feasible to increase the separate collection of textile products, especially those with highly valuable materials. Directive 2008/98/EC requires Member States to ensure the separate collection of textiles by 2025. Moreover, a proposal for a targeted revision of this Directive is currently in co-decision and is expected to introduce more detailed collection and sorting requirements and the establishment of Extended Producer Responsibility (EPR) for certain textile and footwear products in Member States.

Environmental aspects

The impacts from the fashion industry include over 92 million tonnes of waste produced per year, accounting for up to 22% of mixed waste worldwide (Niinimäki et al., 2020). As mentioned in section 3.3.2 of the 1st milestone, the EU generated in 2019 around 12.6 Mt of textile waste. Around 86% of that waste is post-consumer waste. The current management of textile waste is considered suboptimal, as landfilling and incineration are the predominant treatment methods (Solis et al., 2024), releasing harmful substances and contributing to global warming, among other environmental impacts.

In Europe, on average 37% of textiles waste are separately collected (Amicarelli et al., 2022). The majority of post-consumer waste that is separately collected is sent outside the EU as used products intended for re-use. However due to the saturation of the global market for such used products many items are instead discarded in third countries causing negative environmental and social impacts (Huygens et al., 2023).

Strategies aiming at reducing the amount of waste generated, or at increasing the amount of textile waste collected and sorted at end of life, would have a significant benefit on the environment.

Socioeconomic

As pointed out in section 5.6 of the 1st milestone, the exports of used textiles from the EU reached 1 700 000 tonnes in 2019. Usually, these products are exported to Africa for a first screening in local markets, then down-cycled into industrial rags or filling, or re-exported to Asia for recycling. A significant amount of this waste ends up in Asian and South American landfills.

Reducing the amount of waste that is sent to landfill could also stimulate the creation of jobs, related to the collection, sorting and recycling of textiles.

The expected generation of waste is directly related with consumers. The apparent consumption of textile apparel has doubled after the opening of the EU market to products coming from China, as explained in section 5.2 of the 1st milestone. Section 6.4.1 the 1st milestone already highlighted the main factors influencing disposal decisions (perceived quality being one of the key aspects). Material defects, inappropriate size, loss of shape, or not liking the item, are also important factors (Kleinhückelkotten et al., 2018). Sharing with social circles, donating or swapping are common ways to dispose of apparel no longer being used. Throwing away usable apparel is generally perceived as a socially reproachable behaviour (despite this, large amounts of textile waste are still generated nowadays, as pointed out above).

Qualitative assessment of relevance

Based on the above, expected generation of waste is considered a relevant product aspect in the context of textile apparel.

2.2 Supporting information on parameters affecting the physical durability

Table 16 reports the main fibre characteristics playing a role in the physical durability of textile apparel. Additionally, **Table 17** and **Table 18** report definitions of yarn and fabric characteristics and main process parameters, respectively. This information supports the description of interlinks among several factors in the textile apparel production.

Table 19 reports the influence of fibre characteristics on yarn and fabric characteristics. **Fibre length** influences the strength, smoothness, and uniformity of the fabric, with longer fibres enhancing the physical performance of yarns and fabrics. **Fibre strength** is critical to the physical durability of the yarn and has a direct impact on the ability of the textile apparel to withstand wear and tear. **Fibre fineness** is important for producing finer yarns, which are essential for creating smoother, softer and more uniform products, enhancing the texture, comfort and appearance of textile apparel. **Fibre elasticity**, which is the ability of fibres to return to their original shape after stretching, is vital for the resilience and shape retention of the fabric. Additionally, the type of fibre, whether natural or chemical, plays a significant role. More details are reported in **Table 19.**

Fibre characteristics are largely influenced by various external factors. **Environmental conditions** such as climate and soil characteristics significantly affect natural fibres, while the diet and health of animals impact the characteristics of fibres like wool and silk. **Chemical exposures**, including pesticides and pollutants, can degrade fibre characteristics. Additionally, the mechanical and chemical processing techniques used during fibre production can alter their strength, elasticity, and overall integrity. Finally, **moisture and temperature during the storage** of fibres plays a crucial role in preventing damage like mould growth or material degradation, ensuring fibres maintain their desired properties (Hearle and Morton, 2008) (Mishra, 2000) (Rahman et al., 2023).

Understanding the influence of fibre characteristics on yarn, processing and fabric is essential for optimizing manufacturing processes and achieving desired textile performance and aesthetics.

Table 16. Description of the main fibre characteristics

<table>
<tr><th>Fibre characteristic</th><th>Definition</th><th>Description of natural fibres</th><th>Description of chemical fibres</th><th>Source</th></tr>
<tr><td>Fibre length</td><td>The length of the individual staple fibre[43]</td><td>Natural fibre lengths are generally categorised into:
Short (S) – Less than 25mm; Medium (M) – 25-30mm; Long (L) – 30-37mm; and Extra Long Staple (ELS) – Over 37mm.

Specific natural fibre lengths:
Silk (continuous): 50 000 to 1 500 000 cm
Hemp: average 182.88 cm
Flax: up to 90 cm
Wool:
• Fine wool: 3.8 to 12.7 cm
• Medium wool 6.35 to 15.24 cm
• Courser or long 12.7 to 38.1 cm
Cotton:
• Very short-staple cotton: ≤2.1 cm
• Short staple cotton: >2.2 cm and <2.5 cm
• Medium Staple cotton: >2.6 cm and < 2.8 cm
• Ordinary long-staple cotton: >2.9 cm and < 3.4 cm
• Extra-long staple cotton: ≥3.4 cm</td><td>Chemical fibre lengths can be considered continuous</td><td>https://textileexchange.org/glossary/fibre-length/

https://www.textilecoach.net/post/cotton-fibre#:~:text=Short%20staple%20cotton%3A%20%3E22mm%20and,staple%20cotton%3A%20%E2%89%A534%20mm

https://www.fao.org/natural-fibres-2009/about/15-natural-fibres/en/</td></tr>
<tr><td rowspan="2">Fibre strength</td><td rowspan="2">The strength of an individual fibre</td><td colspan="2">It is generally measured by tenacity, defined as the breaking force of the fibre divided by the weight of 1000 m of fibre (e.g. cN/tex[44]).
Minimum fibre strength =6 cN/tex is technically acceptable for spinning processes.</td><td>(Lamb, 2009)
https://textilelearner.net/properties-of-silk-fibre/#:~:text=Tenacity%3A,Silk%20loses%20strength%20on%20wetting.
https://omnexus.specialchem.com/polymer-property/strength-at-break-tensile
(Rahman Khan et al., 2011)
https://cmdgroup.in/physical-properties-of-fibres.php
https://old.swicofil.com/products/223polyamideimide.html
https://www.tp-industrial.com/files/specs-polyamide-1.pdf</td></tr>
<tr><td>Significant breaking strengths of most used natural fibres for textile apparel:
Hemp: 65.5-72.5 cN/tex
Silk: 29.1-42.3 cN/tex
Cotton: 15-40 cN/tex
Wool: 12-18 cN/tex
Flax: 7.37 cN/tex</td><td>Significant breaking strengths of most used chemical fibres for textile apparel:
Polyamide: 65-82 cN/tex
Polyester: 35-60 cN/tex
Acrylic: 19.6-29.4 cN/tex
Viscose: 19.6 cN/tex
Acetate: 12.7 cN/tex</td><td></td></tr>
</table>

[43] Considering that man-made fibres are assigned infinite length.
[44] cN/tex= centi Newton / Tex is a unit allowing to qualify the elastic capacity of a textile or a yarn

Fibre characteristic	Definition	Description of natural fibres	Description of chemical fibres	Source
Fibre cleanliness	Refers to the degree of fibre contamination with impurities[45]	Impurities are classified into ranges and according to the impurities grade and are mainly common in natural fibres, but they can appear in chemical fibres due to the treatment agents such as lubricants and oils in chemical fibres production.		http://www.definetextile.com/2013/04/fibre-cleanliness.html
		Range of impurities: • ≥7 %- Very dirty • 4-7 %- Dirty • 2-4%- Medium • 1.2-2- Clean • ≤1.2- Very clean Impurities grade (AFIS[46]): • ≤15 µm- Breathable dust • 15-50 µm- Micro dust • 50-500 µm- Dust • ≥500 µm-Trash		
Fibre fineness	Determines the number of fibres that can made up the cross-section of a yarn with a specific thickness.	Measures units of mass per unit of length to assess linear density (e.g. dtex[47]) According to the classification of Sekhri (Sekhri, 2016), fibre fineness can be classified as it follows: • Thick fibres >7 dtex • Semi-fine fibres: 7-2.4 dtex • Fine fibres: 2.4-1 dtex • Microfibres: 1-0.3 dtex • Super microfibres <0.3 dtex		http://www.definetextile.com/2013/04/fibre-fineness.html
		Hemp: 48.1–186.9 dtex **Wool:** 3.5 dtex **Flax:** 1.39- 1.7 dtex **Cotton:** 1.6 dtex **Silk:** 0.95-1.6 dtex	The minimum fineness that the raw material and technology permits obtaining for the conventional applications is presented below, considering that the fineness can be increased depending on the application: **Polyester:** 0.8-3 dtex (ultrafine or microfibre 0.55 dtex) **Polyamide:** minimum 1 dtex **Acrylic:** minimum 0.9 dtex **Viscose:** minimum 1.2 dtex **Acetate:** minimum 1.5 dtex	(Ramey, 2018) (Fibre Fineness - an overview | ScienceDirect Topics, n.d.) (Rahman Khan et al., 2011) (Banale, 2017) (Chapter 3. Fibre fineness and transverse dimensions, 2008) (Goudar and Kulloli, 2022)

[45] The impurities may be natural from the cultivation process, but also generated by processing. Generally, impurities must be eliminated via a cleaning process.
[46] AFIS (Advanced Fibre Information System)
[47] dtex (deci-tex): Grams per 10.000 metres of yarn

Fibre characteristic	Definition	Description of natural fibres	Description of chemical fibres	Source
Fibre colour	The colour of the fibre affects the ability of a yarn or fabric to be to dyed or bleached.	The performance of yarn during dyeing or bleaching is influenced by the natural colour of the fibre. This characteristic is mainly relevant to natural fibres. The colour of man-made fibres can be controlled during the production process.	This does not apply to chemical fibres.	https://www.fao.org/natural-fibres-2009/about/15-natural-fibres/en/
Fibre stiffness	Fibre stiffness refers to the ability of a fibre to resist deformation or bending when subjected to a load	Commonly measured using parameters like Young's modulus or bending modulus, which characterise the material resistance to deformation. It depends on the fibre substance and the relationship between fibre length and fibre fineness: • The length of the fibre is proportional to the bending modulus. The following relationship can be indicated: • Thick fibres are generally stiff, firm and wrinkle-resistant. Fine fibres are soft, flexible and generate good drape.		(Ferrándiz et al., 2021)

Source: own knowledge and sources indicated in the table

Table 17. Definitions of yarn and fabric characteristics

Intermediate textile product	Characteristic	Definition	Source
Yarn	Evenness	Yarn evenness refers to the uniformity of the yarn in terms of thickness and weight along its length.	(Elmogahzy, 2019)
	Hairiness	Yarn hairiness refers to the presence and extent of fibre ends and loops protruding from the main body of the yarn.	(Elmogahzy, 2019)
	Strength	Yarn strength refers to the ability of a yarn to withstand tensile forces without breaking.	(Elmogahzy, 2019)
	Appearance	Yarn appearance refers to the visual and physical characteristics of yarn, including diameter, hairiness, and defects, which affect its performance and the physical durability of the final fabric.	(Tahvildar et al., 2019; Li et al., 2020)
Fabric	Handle	Fabric handle refers to the tactile qualities of a fabric, encompassing its softness, smoothness, flexibility, and overall sensation when touched, which contribute to its comfort and user experience	(Tahvildar et al., 2019; Li et al., 2020)
	Lustre	The visual aspect of a fabric or yarn that reflects light in a way that creates a shiny or glossy appearance.	(Kim et al., 2004)
	Strength	Fabric strength can be defined as the ability of a fabric to withstand various forces and stresses without breaking or deforming	(Mobarak Hossain, 2016)
	Appearance	Fabric appearance encompasses the overall look and visual appeal of the fabric, which is influenced by factors such as weave structure, yarn compactness, and finishing processes.	(Tahvildar et al., 2019)
	Drape	Fabric drape refers to how the fabric hangs in three dimensions, retaining its shape from when it is laid flat or adapting to new contours.	(Choudhary and Bansal, 2017)
	Smoothness	Fabric smoothness refers to the fabric surface resistance to a sliding tangential force applied.	(Mao et al., 2016)
	Softness	Fabric softness refers to the tactile sensation or comfort level experienced when touching or wearing a fabric.	(Ferrándiz et al., 2021)
	Breathability	Breathability in fabrics is the ability of water vapours to successfully permeate through that fabric via diffusion and, henceforth, facilitate cooling via evaporation.	(İnovenso Teknoloji Ltd.Şti and Mustafa, 2023)
	Insulation	Fabric insulation refers to a fabric's ability to retain heat and provide warmth by reducing the transfer of heat from the body to the surrounding environment.	(Matusiak Malgorzata and Sikorski Renata, 2011)
	Anti-wrinkle	Anti-wrinkle is a finishing method for textiles that prevents creases and wrinkles, enhancing the appearance of the articles.	(Van den Bergen and Parker, 2023)

Intermediate textile product	Characteristic	Definition	Source
	Resistance to stains and water	Resistance to stains refers to the ability of a fabric to repel or prevent the absorption of various staining substances, thereby maintaining its appearance and cleanliness over time. Resistance to water, also known as water repellency, describes the capacity of a fabric to prevent water from penetrating its surface, thus keeping the material dry and maintaining its structural integrity.	(Rowen and Gagliardi, 1947) (Roy Choudhury, 2017)

Source: AITEX's knowledge and references reported in the last column

Table 18. Definitions of main process parameters

Process parameter	Definition	Sources
Spinning method	The spinning method encompasses various techniques used to transform raw fibres into yarn. These methods involve processes that draw out and twist the fibres, creating a continuous strand of yarn. For detailed descriptions of different spinners, refer to section 9.2.2 of the 1st milestone.	(Elmogahzy, 2019) (Sinha and Chattopadhyay, 2007) (Mahmoudi, 2010) (Tyagi, 2010) (Mobarak Hossain, 2016) (Rahman et al., 2023)
Spinning limit	The spinning limit defines the range of yarn counts achievable from a given fibre using a specific spinning system. It depends on the number and thickness of individual fibres (for natural fibres) or filaments (for chemical fibres) twisted together.	
Spinning Productivity	Spinning productivity can be defined as the production of the finest yarn count from a given fibre ensuring acceptable performance and minimising end breakage rates.	
Twist level	Twist level is defined by the number of turns per unit length (per inch or per meter) in a spun yarn. It describes yarn density.	
Twists number	The twist number quantifies the number of turns about its axis per unit length of a yarn or textile strand. It is expressed as turns per inch (TPI), turns per meter (TPM), or turns per centimetre (TPCM).	
Spinning tension	Spinning tension represents the resistance or force applied to the yarn during the spinning process.	
Speed of spinning	The speed of spinning defines the rate at which fibres are converted into yarn during spinning.	
Rolling, revolving, and twisting movements	These fundamental movements in spinning: Rolling: Rotation of fibres to align them, Revolving: Circular motion of the spindle, Twisting: Imparting twists to the fibres, resulting in yarn formation	
Yarn manufacturing process development	Encompasses the life cycle stage for converting raw fibres into yarn.	
Conditioning (steaming)	It involves moistening the yarn using saturated steam or wet steam.	
Spinning twist limit	The spinning twist limit defines the upper range of yarn count achievable for a given fibre and spinning system, determining the maximum fineness of yarn produced.	
Temperature and humidity control	Maintaining optimal temperature and humidity levels is crucial. High humidity improves yarn properties, while excessive moisture can lead to issues.	
Dyeing process	Dyeing involves applying colour to yarn or fabric.	
Characteristics of components and machinery	The characteristics of components and machinery directly affects yarn production. Well-maintained, precise equipment ensures consistent yarn properties.	
Defects control	Defect control focuses on minimising flaws in yarn, such as knots or irregularities, enhancing yarn desired performances, and reducing waste.	
Thread count	Thread count refers to the number of yarns (threads) per unit length in woven fabrics, and it affects fabric density and texture.	
Weight of fabric	The weight of fabric is determined by the total mass of yarn used per unit area, influencing fabric thickness and durability.	

Process parameter	Definition	Sources
Weave pattern	The weave pattern describes how warp and weft yarns interlace to form fabric	

Source: AITEX's knowledge and references reported in the last column

Table 19 Influence of the fibre characteristics on yarn and fabric characteristics and parameters of manufacturing processes

Characteristic or parameter		Fibre length (1)	Fibre strength	Fibre cleanliness	Fibre fineness	Fibre colour	Fibre stiffness (2)
Yarn characteristics	Evenness	Yarn evenness increases during drafting[48] proportionally with the fibre length.	Yarn evenness increases proportionally with the increase of fibre strength (smaller extent).		Yarn evenness increases proportionally with the increase of fibre fineness. (5)		
	Hairiness (3)	Yarn hairiness decreases with the increase of fibre length.	Yarn hairiness decreases with the increase of fibre strength.		Yarn hairiness increases with the increase of fibre fineness. (5)		
	Strength	Yarn strength increases proportionally with fibre length increase.					
	Appearance			Yarn appearance improves with the increase of fibre cleanliness. (4)			
Yarn manufacturing (spinning) parameters	Twist limit				Twist limit decreases with the increase of fibre fineness, after the optimal working range.		
	Spinning limit	Spinning limit increases proportionally with the increase of fibre length.	Spinning limit increases proportionally with the increase of fibre strength.		Spinning limit increases proportionally with the increase of fibre fineness.		
	Spinning productivity	Spinning productivity increases with the increase of fibre length.	Spinning productivity increases with the increase of fibre strength.		Spinning productivity increases with the increase of fibre fineness.		

[48] Drafting is the process of reducing the thickness of fibres to achieve specific fineness and strength for yarns (Rahman et al., 2023).

Characteristic or parameter		Fibre length [1]	Fibre strength	Fibre cleanliness	Fibre fineness	Fibre colour	Fibre stiffness [2]
	Rolling, revolving, and twisting movements						
	Spinning process development			Spinning process improves with the increase of fibre cleanliness. [4]			Spinning process worsens with the increase of fibre stiffness.
Finishing processes parameters	Dyeing					Dyeing process efficiency decreases with the increase of fibre natural colour. [6]	
Fabric characteristics	Handle	Fabric softness increases with the increase of fibre length.			Fabric softness increases with the increase of fibre fineness.		
	Luster	Fabric shininess increases with the increase of fibre length.			Fabric shininess increases with the increase of fibre fineness.		
	Strength		Fabric resistance to tear strength increases with the increase of fibre strength.				
	Appearance			Fabric appearance improves with the increase of fibre cleanliness. [4]			
	Drape				Fabric drape improves with the increase of fibre fineness.		

([1]) Most commonly related to natural fibres and mechanically recycled synthetic or other man-made fibres. It defines the spinnability of the fibre.
([2]) A fibre that is too stiff has difficulty in adapting to process movements. The lower the springiness generates more creation of neps (entangled and knotted fibres generated by increased stiffness).
([3]) Unwanted parameter
([4]) Impurities generate a bad yarn drying, with broken ends increased, generating a worse appearance. Additionally, impurities interfere with the process development affecting the strength of the material to be processed. Finally, impacts the appearance and physical characteristics of the fabric and finished product.
([5]) A finer the fibre allows a multitude of fibres/filaments in the cross-section, allowing a better distribution in the yarn. Fibre fineness decreases after the optimal working range and yarn hairiness will increase.
([6]) The intrinsic colour of the fibre interferes with the dyeing process.

*Source: AITEX's knowledge and **Figure 1***

Yarn manufacturing, the spinning process combining rolling, revolving and twisting movements, is defined by parameters that influence the final yarn characteristics.

Table 20 reports the effect of main process parameters on the characteristics of the yarn. The selection of the spinning method influences the evenness, softness and strength of the yarns. Nevertheless, the twist level and number impact the strength and softness of the yarns. Controlling optimal spinning tension and speed is important due to the impact on the strength of the yarn. Proper yarn conditioning has the potential to enhance characteristics such as flexibility, strength and evenness. Manufacturing process parameters such as temperature and humidity control and the characteristics of components and machinery, completed with performance control, influence overall the mechanical-related strength of the yarns.

Understanding and controlling these processing parameters enables manufacturers to customise yarn characteristics for precise end applications, like textiles for fashion such as underwear, jackets, or accessories. Adjustments in these parameters can result in notable differences in yarn physical performance and durability, demonstrating the importance of precise control and monitoring during the spinning process.

Table 20. Influence of spinning parameters on yarn characteristics

<table>
<tr><th>Yarn characteristics</th><th>Spinning method</th><th>Twist level</th><th>Twists number</th><th>Spinning tension (²)</th><th>Speed of spinning</th><th>Conditioning (steaming)</th><th>Temperature and humidity control</th><th>Characteristics of components and machinery</th><th>Defects control</th></tr>
<tr><td>Yarn evenness</td><td>Air-Jet Spinning → highly uniform yarns</td><td></td><td></td><td>Constant tension: uniform yarn</td><td></td><td>Enhances evenness</td><td rowspan="4">Proper humidity prevents static electricity, material processing issues, equipment damage, and fabric shrinkage.</td><td rowspan="4">High quality of the machinery produces consistent yarns.

Ensures improved efficiency, safety, productivity, and product performance</td><td rowspan="4">Critical for maintaining high-performance standards and preventing imperfections in yarn and fabric</td></tr>
<tr><td>Yarn elasticity</td><td></td><td></td><td></td><td></td><td></td><td>Enhances flexibility</td></tr>
<tr><td>Yarn softness</td><td>Air-Jet Spinning → highly smooth yarns</td><td>Low Twist: softer yarns</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Yarn strength</td><td>Ring Spinning→ very high-strength and finer yarns
Rotor (Open-End) Spinning → bulkier yarns with reduced strength
Air-Jet Spinning → less durable yarns</td><td>High Twist: stronger yarns</td><td>Yarn strength increases with twist to a peak (¹), then decreases.</td><td>Uneven Tension: can cause breakages during subsequent processing</td><td>Higher Speeds: can cause breakages</td><td>Enhances strength</td></tr>
</table>

(1) Optimal twist depends on fibre length, fineness, strength, and friction.
(2) Spinning tension: Essential for evaluating ring spinning machine performance.

*Source: AITEX's knowledge and **Figure 1***

In the **fabric manufacturing**, the industry opts for either weaving or knitting techniques, depending on the intended use of the final products. The parameters involved in weaving significantly impact the characteristics of the fabric. These are the yarn count, weight of fabric, and weave pattern, among others. **Table 21** reports the influence of the main weaving parameters on the fabric characteristics. A higher thread count defines smoother, softer, and more breathable fabrics. Meanwhile, the weight of the fabric improves the resistance to tear but decreases breathability and drape. Finally, the selection of the weave pattern impacts the resistance to tear and is done according to the desired functionality, such as smoothness, anti-wrinkle, and resistance to stains and water.

Table 21. Influence of weaving parameters on fabric characteristics

Parameter	Type	Fabric characteristic							
		Smoothness	**Softness**	**Breathability**	**Tear strength**	**Insulation**	**Anti-wrinkle**	**Resistance to stains and water**	**Drape**
Thread count (1)	Higher the number of threads	Increases fabric smoothness	Increases fabric softness	Decreases fabric breathability					
Weight of fabric (2)	Heavier fabric			Decreases fabric breathability	Increases resistance to tear	Increases fabric insulation properties			Decreases fabric drape
Weave pattern (3)	Plain (eg. Chiffon, organza)	Increases fabric smoothness		Increases fabric breathability					
	Diagonal (eg. twill)				Increases resistance to tear		Increases fabric anti-wrinkle capacity	Increases fabric resistance to stains and water	
	Satin	Increases fabric smoothness			Decreases fabric resistance to tear				

(1) Generally, more important for fabrics intended to be used in contact with the skin (e.g. beddings, textile apparel). The optimal thread count can vary depending on the desired fabric use and feel, and sometimes higher thread counts are achieved by using multiple-ply yarns, which can affect the fabric differently.

(2) The weight is influenced by the yarn's thickness and the tightness of the weave or knit. Generally more important for fabrics such as upholstery or drapery.

The fabric construction parameters, including weave pattern, yarn count, fabric thickness, and compaction, influence tear strength. Fabrics with denser weaves, higher yarn counts, and thicker constructions tend to exhibit higher tear resistance.

The weight or mass of the fabric per unit area is indicative of fibre concentration and arrangement. Heavier fabrics with higher yarn density typically offer better tear strength. The denser packing of fibres in the fabric structure increases resistance to tearing forces.

(3) Each weaving pattern offers unique characteristics that can be leveraged for specific applications, impacting not only the aesthetics of the fabric but also its performance in various uses

*Source: AITEX's knowledge and **Figure 1***

Table 22 reports the influence of finishing processes on fabric characteristics. **Fabric finishing** is a crucial stage in manufacturing that imparts specific aesthetic and technical functionalities to the fabric. **Dyeing** plays a significant role, as the choice of dye and dyeing technique can greatly influence colour fastness ([49]), hand feel, colour depth, and evenness. Table 46 in section 9.2.4 of the 1st milestone reports information on the relationship between fibre type and dye affinity. **Printing** affects the vibrancy of colours and the handle of the fabric. **Chemical finishing** imparts various properties to the fabric, such as improved handle and repellency to water, oil, and stains, thereby enhancing its physical durability. Mechanical finishing alters the fabric's physical properties, contributing to smoothness or improving the handle, such as adding fluffiness. **Coating and laminating** processes are used to enhance fabric performance by adding waterproofing capabilities and increasing breathability or resistance to abrasion (Rahman et al., 2023).

Table 22. Influence of finishing processes on fabric characteristics

Finishing process type	Primary influence on fabric characteristics
Dyeing	Colour depth, evenness, and fastness
Printing	Pattern precision, vibrancy, and hand feel
Chemical Finishing	Functional properties like softness, repellence
Mechanical Finishing	Physical properties like smoothness, plushness
Coating and Laminating	Protective and performance-enhancing characteristics such as waterproofing, breathability

*Source: AITEX's knowledge and **Figure 1***

Three main components affect the physical durability during **confectioning** of the textile apparel: the sewing physical characteristics, precision of cuts, and seam strength. **Sewing physical characteristics** include the straightness of seams, consistency of stitch length, and the absence of skipped stitches. These affect both the appearance and physical durability of the textile apparel. The **strength and type of seams** used in fabric assembly determine the physical durability of the textile apparel and its ability to endure wear and stress. Inadequately constructed seams may result in rapid deterioration. **Precise cutting** following patterns is essential for ensuring that the textile apparel fits properly. Mistakes in cutting can result in poorly fitting textile apparel, directly affecting consumer satisfaction (Rahman et al., 2023) (Elhawary, 2015b).

49 Colour fastness refers to the resistance of a fabric's colour to fading or running when exposed to various conditions, such as washing, sunlight, rubbing, and perspiration

2.3 Supporting information on test methods to describe the physical durability

Table 23. Description of standardised test methods to assess key parameters of physical durability

Parameter	Testing method	Short description of the scope of the test	Type of result obtained
Abrasion resistance	ISO 12947-2:2016[50] Textiles — Determination of the abrasion resistance of fabrics by the Martindale method Part 2: Determination of specimen breakdown	It specifies a method for determining the abrasion resistance of textile fabrics using the Martindale method, by determining when a textile fabric reaches breakdown by inspecting it at regular intervals. It applies to all textile fabrics, including nonwovens, except for fabrics with a specified low abrasion wear life. These results help to determine the durability and longevity of the fabric when subjected to repetitive friction.	Number of rubs or cycles The results are typically expressed as the Number of Rubs or Cycles, which indicates the number of abrasion cycles the fabric can withstand before showing significant wear or damage.
Bursting resistance	ISO 13938-2:2019 [51](50cm^2) Textiles — Bursting properties of fabrics. Part 2: Pneumatic method for determination of bursting strength and bursting distension	It specifies a method for determining the bursting strength and expansion of textile fabrics using a pneumatic method. When tested using a specimen size of 50 cm^2. These measurements provide critical information about the fabric's resistance to pressure and its ability to stretch before failing.	Kilopascals (kPa) The results are typically expressed as kilopascals (kPa), indicating the pressure required to burst the fabric.
Colour fastness to chlorinated water	ISO 105-E03:2010[52] Textiles - Tests for colour fastness - Part E03: Colour fastness to chlorinated water (swimming-pool water) (ISO 105-E03:2010)	It specifies a method for determining the resistance of textile colours, on fabrics, to active chlorine, like the concentrations used in swimming pool water for disinfection. These grades indicate how well a fabric's colour resists fading and staining when exposed to chlorinated water, which is crucial for textiles used in swimwear and other water-related applications.	Grading scale The results obtained from this test are typically expressed as Colour Fastness Grade: This is assessed using the Grey Scale for Colour Change and the Grey Scale for Staining, which range from 1 to 5, where: Grade 1: Very poor colour fastness. Grade 2: Poor colour fastness. Grade 3: Moderate colour fastness. Grade 4: Good colour fastness. Grade 5: Excellent colour fastness.
Dimensional change	ISO 3759:2011[53] Textiles — Preparation, marking and measuring of fabric specimens and textile apparel in tests for determination of dimensional change	Provides a method for preparing, marking, and measuring textile fabrics, textile apparel, and fabric assemblies to test how they change in size after treatments like washing, dry cleaning, soaking, or steaming. These treatments must follow procedures from specific ISOs. It applies to woven and knitted fabrics and finished textile articles but does not apply to certain upholstery coverings.	Percentage (%) This percentage reflects the dimensional change, such as shrinkage or stretching of the fabric after washing or dry cleaning. The percentage change is calculated based on the difference between the original and the post-treatment dimensions.
Elasticity of fabric	ISO 20932-3:2018[54]	It specifies a method for determining the elasticity of textile fabrics using a cyclic testing procedure. These results help to assess the fabric's ability to recover its	Percentage (%) When tested after one minute, the results are typically expressed as extension at specified load: Measured in

[50] ISO 12947-2:2016 Textiles — Determination of the abrasion resistance of fabrics by the Martindale method Part 2: Determination of specimen breakdown. Available at this link.
[51] ISO 13938-2:2019 Textiles — Bursting properties of fabrics Part 2: Pneumatic method for determination of bursting strength and bursting distension. Available at this link.
[52] ISO 105-E03:2010 Textiles — Tests for colour fastness Part E03: Colour fastness to chlorinated water (swimming-pool water). Available at this link.
[53] ISO 3759:2011 Preparation, marking and measuring of fabric specimens and textile apparel in tests for determination of dimensional change. Available at this link.
[54] ISO 20932-3:2018 Textiles — Determination of the elasticity of fabrics Part 3: Narrow fabrics. Available at this link.

Parameter	Testing method	Short description of the scope of the test	Type of result obtained
	Textiles — Determination of the elasticity of fabrics Part 3: Narrow fabrics	original shape after being stretched, which is important for applications where elasticity and shape retention are critical.	percentage (%), this indicates the amount of stretch or elongation that occurs when a specified load is applied to the fabric.
Colour fastness to artificial light	ISO 105-B02: 2014[55] Textiles — Tests for colour fastness Part B02: Colour fastness to artificial light: Xenon arc fading lamp test	It specifies a method for determining the colour fastness of textile fabrics to artificial light: the Xenon arc fading lamp test, outlining a method for testing how the colour of textiles, including white or bleached fabrics, reacts to artificial light similar to natural daylight (D65). It allows the use of two different sets of blue wool references, though the results from these references may vary. These grades indicate how well a fabric's colour resists fading when exposed to artificial light, which is crucial for maintaining textiles' appearance over time.	Grading scale The results are typically expressed as Colour Fastness Grade: This is assessed using the Blue Wool Scale, which ranges from 1 to 8, where: Grade 1: Very poor light fastness. Grade 2: Poor light fastness. Grade 3: Moderate light fastness. Grade 4: Fair light fastness. Grade 5: Good light fastness. Grade 6: Very good light fastness. Grade 7: Excellent light fastness. Grade 8: Outstanding light fastness.
Pilling resistance	ISO 12945-2:2020[56] (2000 cycles) Textiles — Determination of fabric propensity to surface pilling, fuzzing or matting Part 2: Modified Martindale method	Tests of textiles' pilling resistance are typically expressed as pilling grade. This is a visual assessment of the fabric surface after it has been subjected to 2000 cycles of abrasion.	Grading scale The grading scale usually ranges from 1 to 5, where 1 indicates severe pilling and 5 indicates no pilling. Grade 1: Severe pilling with dense pilling covering the entire fabric surface. Grade 2: Pronounced pilling with significant pilling affecting a large area of the fabric. Grade 3: Moderate pilling with noticeable pilling over a moderate area of the fabric. Grade 4: Slight pilling with some pilling visible but not extensive. Grade 5: No pilling with no visible pilling on the fabric surface.
Colour fastness to sea water	ISO 105-E02:2013[57] Textiles — Tests for colour fastness Part E02: Colour fastness to sea water	It specifies a method for determining the colour fastness of textiles to sea water. These grades indicate how well a fabric's colour resists fading and staining when exposed to sea water, providing important information for textiles intended for marine or coastal use.	Grading scale The results obtained from this test are typically expressed as Colour Fastness Grade: This is assessed using the Grey Scale for Colour Change and the Grey Scale for Staining, which range from 1 to 5, where: Grade 1: Very poor colour fastness. Grade 2: Poor colour fastness. Grade 3: Moderate colour fastness. Grade 4: Good colour fastness.

[55] ISO 105-B02:2014 Textiles — Tests for colour fastness Part B02: Colour fastness to artificial light: Xenon arc fading lamp test. Available at this link.
[56] ISO 12945-2:2020 Textiles — Determination of fabric propensity to surface pilling, fuzzing or matting Part 2: Modified Martindale method. Available at this link.
[57] ISO 105-E02:2013 Textiles — Tests for colour fastness Part E02: Colour fastness to sea water). Available at this link.

Parameter	Testing method	Short description of the scope of the test	Type of result obtained
			Grade 5: Excellent colour fastness.
Seam resistance	ISO 13935-2:2014[58] Textiles — Seam tensile properties of fabrics and made-up textile articles Part 2: Determination of maximum force to seam rupture using the grab method	It specifies a method for determining the seam strength of textile fabrics by using the grab method, indicating methods for determining the maximum force of sewn seams when force is applied perpendicularly, using the grab test. It primarily applies to woven fabrics, including those with stretch characteristics, but may also apply to other fabric types. These measurements provide critical information about the strength of textile fabrics, which is essential for ensuring the durability and performance of sewn products.	Newtons (N) The results are typically expressed as Seam-Breaking Force measured in Newtons (N); this indicates the force required to break the seam.
Tensile strength	ISO 13934-1:2014[59] Textiles — Tensile properties of fabrics Part 1: Determination of maximum force and elongation at maximum force using the strip method	This specifies a method for determining the maximum force and elongation at the maximum force of textile fabrics using a strip method. It mainly applies to woven fabrics, including those with stretch properties from elastomeric fibres, and mechanical or chemical treatments.	Newtons (N) This value reflects the maximum force, which indicates the highest force the fabric can withstand before breaking.
Visual inspection for: (1) Colour change (2) Pilling (3) Trimmings aspect (4) Self-staining	ISO 15487:2018[60] Textiles — Method for assessing appearance of apparel and other textile end products after domestic washing and drying	It specifies a method for assessing the appearance of apparel and textile products after one or more cleaning cycles. The evaluation includes factors such as colour change, pilling, fuzzing, matting, fabric smoothness, seam appearance, retention of pressed-increases, and damage to components like buttons or fasteners. It applies to any washable textile product, regardless of fabric construction, as supplied by the manufacturer.	Grading scale The grading scale usually ranges from 1 to 5, where 1 indicates severe distortion or damage, and 5 indicates no visible distortion or damage. Grade 1: Severe distortion or damage, significant loss of fabric integrity. Grade 2: Pronounced distortion or damage, noticeable but not severe. Grade 3: Moderate distortion or damage, visible but not significantly affecting the fabric's usability. Grade 4: Slight distortion or damage, minimal and only noticeable upon close inspection. Grade 5: No visible distortion or damage, fabric maintains its original appearance.

Source: cited standards

[58] ISO 13935-2:2014 Textiles — Seam tensile properties of fabrics and made-up textile articles Part 2: Determination of maximum force to seam rupture using the grab method. Available at this link.
[59] ISO 13934-1: 2014 Textiles - Tensile properties of fabrics - Part 2: Determination of maximum force using the grab method. Available at this link.
[60] ISO 15487:2018 Textiles — Method for assessing appearance of apparel and other textile end products after domestic washing and drying. Available at this link.

2.4 Supporting information on maintenance

Table 24. Comparison of international labelling systems

Characteristic	International Care Labelling System (Ginetex)[61]	ASTM Care Labelling System[62]	Canadian Care Labelling System[63]	British Care Labelling System[64]	Japanese Care Labelling System[65]	Australian Care Labelling System[66]	China Care Labelling System[67]	ISO Care Labelling System[68]
Governing Body	GINETEX	ASTM International	Canadian General Standards Board (CGSB)	British Standards Institution (BSI)	Japanese Industrial Standards (JIS)	Standards Australia and ACCC	China National Textile and Apparel Council (CNTAC)	International Organization for Standardization (ISO)
Region	Global	United States	Canada	United Kingdom	Japan	Australia	China	Global (especially for export procedures)
Primary Symbols	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care	Washing, Bleaching, Drying, Ironing, Professional Care
Temperature Units	Celsius	Fahrenheit (with some symbols using Celsius)	Celsius and Fahrenheit	Celsius	Celsius	Celsius	Celsius	Celsius (with some flexibility for export)
Text Requirement	No text required	Text required alongside symbols	Text required alongside symbols (bilingual: English and French)	No text required	Text is often included for clarity	Text required alongside symbols	Text required alongside symbols (Chinese characters)	No text required, but can include text for clarity
Drying Symbols	Includes natural and tumble drying symbols	Tumble drying symbols with specific temperature settings	Tumble and natural drying symbols	Natural and tumble drying symbols	Unique symbols for indoor/outdoor and natural drying	Tumble and line drying symbols	Symbols for tumble drying and line drying, with specific instructions for sunlight exposure	Similar to GINETEX; focuses on export needs

61 Complete information about International Care Labelling System (Ginetex) available here.
62 Complete information about ASTM Care Labelling System available here.
63 Complete information about Canadian Care Labelling System available here.
64 Complete information about British Care Labelling System available here.
65 Complete information about Japanese Care Labelling System available here.
66 Complete information about Australian Care Labelling System available here.
67 Complete information about Chinese Care Labelling System available here.
68 Complete information about ISO Care Labelling System available here.

Characteristic	International Care Labelling System (Ginetex)[61]	ASTM Care Labelling System[62]	Canadian Care Labelling System[63]	British Care Labelling System[64]	Japanese Care Labelling System[65]	Australian Care Labelling System[66]	China Care Labelling System[67]	ISO Care Labelling System[68]
Bleaching Symbols	Basic symbols for chlorine and non-chlorine bleach	Detailed symbols for bleach types	Specific symbols for non-chlorine bleach	Similar to GINETEX	Specific symbols for bleach types, including traditional care	Similar to GINETEX	Specific symbols for chlorine and non-chlorine bleach, with detailed instructions	Basic symbols for chlorine and non-chlorine bleach
Ironing Symbols	Dots indicating heat level	Dots indicating heat level	Dots indicating heat level	Dots indicating heat level	Dots with additional instructions	Dots indicating heat level	Dots indicating heat level, with additional instructions on steam use	Dots indicating heat level
Professional Care Symbols	Basic dry cleaning and wet cleaning symbols	Detailed symbols for professional care	Basic symbols for dry and wet cleaning	Similar to GINETEX	Detailed symbols including specific letters for different cleaning methods	Similar to GINETEX	Detailed symbols including specific letters for different cleaning methods	Basic dry cleaning and wet cleaning symbols
Language and Accessibility	Universal symbols for easy understanding	Text and symbols for detailed instructions	Symbols with bilingual text (English/French)	Universal symbols to minimize language barriers	Uses both symbols and text, considering Japanese consumers	Uses both symbols and text	Symbols with accompanying text in Chinese for clarity	Universal symbols for global understanding
Legal Requirements	Voluntary but widely adopted	Mandatory compliance with FTC regulations	Mandatory under the Canadian Textile Labelling Act	Voluntary but widely followed in Europe	Mandatory for domestic manufacturers	Mandatory compliance with Australian Standards	Mandatory compliance under Chinese standards	Voluntary for global standardization

Source: own production

2.5 Supporting information on repairability

This section reports a simple analysis of professional repair prices against the prices of the new items of textile apparel. **Table 25** reports the interval of the relative repair price in EU, which takes into account the price intervals of some repair operations carried out by professional repairers and the price intervals of some new items. The analysis shows that repairing an item of textile apparel could be many times more expensive than buying a new item.

Table 25. Comparison between price of professional repair operations and price of new items of textile apparel

Priority part	Failure type	Repair price (EUR)		Items of textile apparel	New item price (EUR)		Relative repair price (%)	
		Min	Max		Min	Max	Min	Max
Fabric	Fabric breakdown	3	9	T-Shirts	3	22	14	300
	Pilling	8	24	Apparel accessories	2	41	20	1 200
				Dresses, Skirts & Jumpsuits	6	90	9	400
				Jackets & Coats	7	589	1	343
				Leggins, stockings, tights and socks	1	19	42	2 400
				Pants & Shorts	3	66	12	800
				Shirts & Blouses	3	90	9	800
				Sweaters and midlayers	3	85	9	800
				Swimsuits	8	74	11	300
				T-Shirts	3	22	36	800
	Stains	3	51	Apparel accessories	2	41	7	2 550
				Dresses, Skirts & Jumpsuits	6	90	3	850
				Jackets & Coats	7	589	1	729
				Leggins, stockings, tights and socks	1	19	16	5 100
				Pants & Shorts	3	66	5	1 700
				Shirts & Blouses	3	90	3	1 700
				Sweaters and midlayers	3	85	4	1 700
				Swimsuits	8	74	4	638
				T-Shirts	3	22	14	1 700
Seam	Hole(s) in seams	3	32	Apparel accessories	2	41	7	1 600
				Dresses, Skirts & Jumpsuits	6	90	3	533
				Jackets & Coats	7	589	1	457
				Leggins, stockings, tights and socks	1	19	16	3 200
				Pants & Shorts	3	66	5	1 067
				Shirts & Blouses	3	90	3	1 067
				Sweaters and midlayers	3	85	4	1 067
				Swimsuits	8	74	4	400
				T-Shirts	3	22	14	1067
Trim	Buttons	1	8	Apparel accessories	2	41	2	400
				Dresses, Skirts & Jumpsuits	6	90	1	133
				Jackets & Coats	7	589	0	114
				Leggins, stockings, tights and socks	1	19	5	800
				Pants & Shorts	3	66	2	267

Priority part	Failure type	Repair price (EUR)		Items of textile apparel	New item price (EUR)		Relative repair price (%)	
		Min	Max		Min	Max	Min	Max
				Shirts & Blouses	3	90	1	267
				Sweaters and midlayers	3	85	1	267
				Swimsuits	8	74	1	100
				T-Shirts	3	22	5	267
	Zips	6	32	Apparel accessories	2	41	15	1 600
				Dresses, Skirts & Jumpsuits	6	90	7	533
				Jackets & Coats	7	589	1	457
				Leggins, stockings, tights and socks	1	19	32	3 200
				Pants & Shorts	3	66	9	1 067
				Shirts & Blouses	3	90	7	1 067
				Sweaters and midlayers	3	85	7	1 067
				Swimsuits	8	74	8	400
				T-Shirts	3	22	27	1 067

Prices are reported without VAT. Repair price were sourced from websites reported in **Table 26**.

$$Relative\ repair\ price\ (\%) = \frac{price\ of\ repair}{price\ of\ new\ apparel\ textile} * 100$$

Source: own elaboration based on (Cooper and Claxton, 2022) *and Statista* [69]*.*

Table 26. Repair shops and dry cleaners consulted for the analysis reported in **Table 25**

Type	Country	Link
Repair shop	Spain	https://arreglosderopabarcelona.es/tarifas-precios-arreglos-ropa/ https://www.pepevera.com/lista_precios
	Romania	https://www.croitoriepentrutoti.ro/preturi/ https://www.urbanwash.ro/images/lista-croitorie-arad.pdf https://atelierdecroitorie.ro/servicii-si-preturi https://www.atelier-croitorie.com/lista-preturi-croitorie-retus
	Ireland	https://paulhenrytailoring.ie/alterations-dublin
	Sweden	https://www.masterarnes.se/skr%C3%A4dderi.html https://www.jeansverket.se/en/jeans/repairs/ https://secondsunrise.se/pages/repairs
	Italy	https://endelea.it/pages/wear-again-textile apparel-restoration-hub
Dry cleaners	Spain	https://tintoreriasronsel.es/tienda/precios-tarifas-y-promociones-de-tintoreria/
	Romania	https://ecoclean.ro/preturi/ https://www.elisse.ro/preturi-spalatorie-haine.html https://www.extraclean.ro/preturi-curatatorie-spalatorie-calcatorie-haine-bucuresti/

Source: reported websites

69 Statista. Available at this link. Last accessed 8 August 2024.

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