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Textile recycling in the **Netherlands**

Considerations for ensuring chemical product safety

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F. Heens | G. Eliesen

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This investigation was performed by order, and for the account, of NVWA, within the framework of the safety of chemicals in consumer products.

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Synopsis

Textile recycling in the Netherlands

Considerations for ensuring chemical product safety

The Dutch government has set the target of achieving a fully circular economy by 2050. This means that by 2050 all raw materials, substances and products should be reused in the same or new applications. Textile products must contain at least 30 percent recycled material by 2030.

Products made from recycled textiles must comply with European legislation on chemicals (REACH). Over the past years, more and more substances have been banned for use in consumer textile products, including plasticisers for prints. RIVM has listed developments related to the reuse of textile products and the recycling of textiles. In addition, RIVM has investigated whether banned chemical substances can end up in textile products due to recycling.
According to RIVM, there is currently a high probability that clothing made from recycled (consumer) textiles meet the legal limits for chemical substances. This conclusion is based on available data on substances in new and collected textiles.

In the current situation, most of the collected textiles from the Netherlands are exported to other countries, where they are worn again. Textile items that are not reusable, for example garments which are torn, are mainly recycled, for example into cleaning cloths for industry or insulation materials. Collected textiles can also be used to make new clothing. This is currently done on a small scale, for example for jeans made from cotton fibres from collected jeans. These fibres are mixed with new cotton fibres, because recycled fibres are less strong than new ones.

Little is known about hazardous chemicals contained in products made from recycled textiles. RIVM recommends drafting a standard protocol for measuring these substances. This is important in order to guarantee safety, also in the long term. RIVM has also listed chemical substances that may be contained in different types of fibre in new and recycled textiles, such as cotton and polyester. This provides manufacturers and users of recycled textiles with an overview of substances to watch out for in specific materials.
To achieve the target for 2030, it is important for clothing to be made in such a way that it can be recycled properly. This means, among other things, that designers should use fewer types of textile fibres for a single garment. And they should make sure that materials can be sorted more easily.

Keywords: circular economy, recycling, textiles, consumer products, risks, opportunities, health

Publiekssamenvatting

Textiel recycling in Nederland

Overwegingen over de chemische productveiligheid

De Nederlandse overheid streeft naar een circulaire economie in 2050. Daarin worden producten, materialen en grondstoffen steeds hergebruikt in dezelfde of nieuwe toepassingen. Dit betekent onder andere dat in 2030 in textielproducten minimaal 30 procent gerecycled materiaal moet zitten.

Producten die gemaakt zijn van gerecycled textiel moeten voldoen aan Europese wetgeving voor chemische stoffen (REACH). De laatste jaren zijn steeds meer stoffen verboden in textielproducten voor consumenten, zoals weekmakers voor prints. Het RIVM heeft de ontwikkelingen van hergebruik van textielproducten en recycling van textiel in kaart gebracht. Ook heeft het onderzocht of er door recyclen verboden chemische stoffen in een product kunnen terechtkomen.

Het RIVM denkt dat de kans nu groot is dat kleding gemaakt van gerecycled (consumenten)textiel, voldoet aan de wettelijke grenswaardes voor stoffen. Het RIVM concludeert dat op basis van beschikbare gegevens over stoffen in nieuw en ingezameld textiel.

Het grootste deel van het ingezamelde textiel uit Nederland wordt nu naar het buitenland geëxporteerd, waar het opnieuw wordt gedragen. Het textiel dat niet herbruikbaar is, bijvoorbeeld omdat het kapot is, wordt vooral gerecycled. Daar worden bijvoorbeeld poetslappen van gemaakt voor in de industrie of isolatiemateriaal. Van het ingezamelde textiel kan ook nieuwe kleding worden gemaakt. Dat wordt nu nog op kleine schaal gedaan bijvoorbeeld voor spijkerbroeken van katoenvezels uit ingezamelde jeans. Deze vezels worden gemengd met nieuwe katoenvezels omdat gerecyclede vezels minder sterk zijn dan nieuwe.

Er is nu nog weinig bekend of er gevaarlijke chemische stoffen zitten in producten die van gerecycled textiel zijn gemaakt. Het RIVM beveelt aan om een standaard protocol te maken om deze stoffen te meten. Dat is belangrijk om de veiligheid te kunnen blijven waarborgen. Ook heeft het van verschillende soorten vezeltypes in nieuw en gerecycled textiel, zoals katoen en polyester, in kaart gebracht welke chemische stoffen erin kunnen zitten. Dat geeft producenten en gebruikers van gerecycled textiel handvatten waar ze bij welke materialen op moeten letten.

Om het doel voor 2030 te halen, is het belangrijk dat kleding zo wordt gemaakt dat het goed te recyclen is. Dat betekent onder andere dat ontwerpers minder soorten textielvezels voor een product gebruiken. Ook moeten zij ervoor te zorgen dat verschillende materialen makkelijker te sorteren zijn.

Kernwoorden: circulaire economie, recycling, textiel, consumentenproducten, risico's, kansen, gezondheid

Contents

Summary

The Dutch government aims to have established a circular economy by 2050 in which products, materials and raw materials are continuously reused for the same or new applications. For textile products, this means that by 2030 they contain 50% of sustainable material of which at least 30% is recycled content. To stimulate this, the government has formulated specific goals and actions for policy makers, businesses and civil society organizations. Initiatives and technologies for textile recycling are emerging rapidly and it is expected that recycled feedstock will form a significant part of future resources to be used.
A large variety of chemical substances is used in textile manufacturing and some remain in the final product intentionally or unintentionally. Some of these chemicals may be harmful to human health and may complicate recycling processes as they may remain in the recycled textile fibres and end up in new textile items. Textiles that are collected today and enter recycling may have been placed on the market several years ago and do not necessarily comply with current regulations with respect to the presences of substances in textile articles as these have been subject to many changes over the past years. Ensuring safety of recycled materials is a prerequisite for achieving circular textile goals and is important for the societal acceptance of recycled textiles.

This project was commissioned by the Netherlands Food and Consumer Product Safety Authority (NVWA) in order to get more insight in the potential chemical risks of recycled textile products to consumers. Hence, the current report provides an overview of the recent developments in textile recycling and describes the potential risks for consumer safety. First, an overview of the textile recycling chain and recycling technologies is provided as well as an overview of policy programmes and legal frameworks. Next, a summary of (hazardous) substances in both new and used textile products (post-consumer textiles) is given and potential risks are discussed where the focus is on compliance with legal frameworks. The report ends with conclusions and recommendations for the NVWA and policy makers.

The textile recycling chain and recycling technologies

Whether a product is suitable for recycling, is determined largely by the fibre composition of the material. Blended materials or for example garments with prints hamper recycling. The materials that serve as input for recycling processes can be divided in three categories. The first, post-production waste, is mostly cutting waste from before a garment is produced. These streams are often well-defined and homogeneous. Second, post-consumer textiles are collected and sorted and overall 35% of this stream is exported for reuse and recycling and 16% is reused or recycled domestically. In the Netherlands, longevity of clothing is estimated to by 4.1 years but garments that are selected for recycling can be much older. Resources for textile recycling may also come from outside the textile industry, which is the final category. Synthetic polymers are used extensively in clothing which can be derived from PET (polyethylene terephthalate) bottles.

Roughly two types of recycling technologies can be distinguished, namely mechanical and chemical recycling. Currently mechanical recycling is the most common. This is a process based on physical forces to create spinnable fibres, fluff or filling material and can be applied to among others wool, cotton and polyester. The fibres can be reused in new garments but need to be blended with virgin (i.e new) fibres in order to maintain high quality the product. Mostly such products are made from 25-50% recycled material. The recovered fibres from mechanical recycling processes are mostly used for more low-grade applications such as cleaning cloths (wipes) and non-woven material (felt) applied as filling or insulation. Little or no chemicals are used during mechanical recycling and hazardous chemicals already present in the input cannot be removed. For polyester, thermo-mechanical recycling can be used to recover polymers in the form or granulates. As heat is applied, chemicals such as chlorinated organic compounds and alkylphenols may evaporate during recycling. Again, chemical consumption of this technique is low.
Chemical recycling is mostly applied to polyester but can now also be applied to cotton blends. For polyester, this involves depolymerization to completely break down the fibres into monomers and makes use of more chemicals compared to mechanical recycling. Chemical recycling is more energy consuming compared to mechanical recycling but the recycled material is of high quality and some hazardous chemicals, such as certain colourants, can be removed during the recycling process.

Policy programmes and legal frameworks

Within the Dutch policy programme for circular economy, the aim for 2030 is to be half-way through the transition. For textile products, this means that products sold in the Netherlands contain 50% of sustainable material. Of that 50%, at least 30% is recycled content and no more than 20% is sustainable material. Additionally, 50% of materials and products sold on the Dutch textile market are recycled after collection, if immediate reuse is no longer possible. The Netherlands also launched the Denim Deal, a public-private initiative to promote the use of post-consumer fibres in denim garments.
At the European level, a textile strategy was presented in 2022 aiming for more high-quality textiles, addressing fast fashion and boosting reuse and repair services. Additionally, the European Commission proposed a Regulation on Ecodesign for Sustainable Products, including textiles. The proposed regulation contains a set of ecodesign performance requirements for textile products, information requirements, and a Digital Product Passport with information on used fibres and substances.
With respect to legal frameworks concerning the use and presences of substances in articles, the Persistent organic pollutants (POPs) Regulation (EC 2019/1021) and REACH Regulation (EC 1907/2006) are most relevant. Under the POP-regulation, several substances are restricted or banned and about some chemical groups have been identified as relevant for textiles such as chlorinated pesticides, certain flame retardants and PFOS and PFOA. Many more substances are restricted under the REACH regulation encompassing certain flame retardants, azo colourants, nonylphenol ethoxylates, some heavy metals and phthalates. Also, CMR substances, among which is formaldehyde (a

widely used anti-creasing agent), are restricted for their use in textile products. There is an ongoing restriction proposal for PFAS and skin sensitizers.
A number of voluntary initiatives exist in the form of labelling schemes and RSLs (restricted substances lists) that have criteria for concentration limits for substances that must not be exceeded. Some RSLs may also take into account substances that are not legally restricted (yet), which can be regarded as a form of self-regulation.

Chemical substances in textile products

Textile manufacturing is a complex process where fabrics can go through pre-treatment, dyeing, printing and finishing processes (e.g. coating and water-proofing) where many chemicals are being used. The chemical content may be reduced during the use-phase when clothes are washed. Nonylphenol ethoxylates, formaldehyde and dyes that are present in excess are easily washed out, but this does not apply to all substances. For example, bisphenol A can even be transferred from one item to another during laundry.

Twelve studies were summarized that provide an overview of measurements of potential hazardous substances in textile products. A wide variety of substances have been measured, with approximately half of the studies focusing on chemical substances for which restrictions are in place. Legal limits were exceeded in some cases. In several items too high levels of nonylphenol ethoxylates were detected. One clothing item contained too high amounts of DEHP and four contained to high amounts of aromatic amines. In outdoor clothing, legal limits of PFOA were sometimes exceeded. In general, data on the actual exposure of humans is lacking.

Two studies were summarized where measurements were specifically performed in post-consumer textiles intended to serve as input for recycling. The largest study was executed by a consortium with H&M and IKEA in the lead. Cotton, wool, and polyester waste from different regions of the world was collected and sampled. Samples were tested on the presence of chemicals according to the restricted substances list (RSL) issued by the AFIRM group capturing the most stringent regulation globally but it is noted that for some substances lower limits have been set. Exact concentrations of substances were not reported is this study. In cotton, four substances were present in concentrations above RSL limits. Alkylphenol ethoxylates were detected most frequently and exceed the RSL limit in 1% of the samples. Bisphenol-A, extractable nickel and extractable chromium also exceeded RSL limits (in respectively 1%, 1% and 2% of the samples), although legal limits are not yet in place for the first two substances. For polyester, mostly chlorobenzenes exceeded RSL limits for which legal limits are not in place. The phthalate DEHP and extractable cadmium (>0.1 mg/kg) were detected in respectively 25% and 17% of the samples. For DEHP it is unclear whether legal limits apply in this situation as the restriction applies to plasticized material only. In wool, the AFIRM RSL thresholds were exceed in almost every sample for varying substances and extractable chromium was detected above the RSL limit in 19% of the samples.

The second study in post-consumer textiles was performed by RISE (Research Institutes of Sweden). In this study, tested chemicals were selected based on relevance for the specific materials and related to OEKO-TEX limit values. Some substances exceeded the OEKO-TEX values, but none exceeded legal limits.

Conclusions and recommendations

Based on the limited studies available we can conclude that the probability that post-consumer cotton complies with current legal thresholds is high.
Based on the available studies it is not possible for polyester to evaluate the potential to comply current legal threshold values. More research is necessary on the presence of DEHP and cadmium. Also PFC's can occur in polyester fabrics, however if the products have no properties as water or dirt repellency, it is expected that these products will meet the legal threshold's for these chemical (groups).
For wool, we can conclude that wool may have difficulties to comply to current legal threshold values. More research is necessary on the presence of extractable chromium (specifically the presence of chromium VI) in recycled wool to verify if it meets the legal thresholds, or not.

If a textile item contains substances above the legal limit, this does not necessarily pose a risk for the consumer as it depends on the actual exposure of the consumer. The same holds true for when such an article is recycled. The safety of a recycled material is for the largest part determined by the quality of the input material. As legal limits are not exceeded in the majority of cases, it is likely that the concentration of substances of concern will drop by the blending with virgin materials. As a result, it is not likely that new articles partly made with recycled material pose a health risk. However, it should be emphasized that guaranteeing safety of new clothing items, that will ultimately serve as input material for recycling, is a prerequisite for ensuring safe textile recycling.

For market surveillance authorities such as the NVWA the following recommendations have been made:

1. Analyse the impacts of increased recycling for the Textile Fibres (EC 100/2011) Regulation.
   Currently, recycled fibres are not clearly indicated on the product label and it is difficult for producers to claim conformity to the Textile Fibres Regulation. As a consequence, transfer of the information to consumers and future recycling processes is hampered. Additionally, it is difficult to monitor the share of recycled content. It is advised to verify whether this regulation hinders realization of circular goals for textiles.
2. Confirm safety of textile products with recycled content by performing additional testing.
   Exposure to chemicals from recycled textiles is not expected to cause health risks for consumers at the moment as it is still in its infancy and mainly applied in cotton articles. In cotton, relatively little substances of concern have been detected, some problematic substances are washed out and prints are usually removed before

recycling. However, as data are scarce, the NVWA could consider to perform additional testing. Such a study could also be useful for communicational purposes as confirming the safety of recycled textile products is important for the societal acceptance of the circular economy.

3. Implement stronger enforcement measures to ensure safety of products from (online platforms) outside of the EU.

Stronger enforcement measures are needed to ensure consumers' safety and to ensure that textiles, once used, can be used safely for the production of new textiles. When it comes to companies selling online, enforcing regulations becomes more difficult. The challenges of the global market and increasingly complex supply chains, as well as the increase in products sold online within the EU, poses many challenges for Market Surveillance Authorities. To this end, it is necessary to enable structured coordination and cooperation between national enforcement authorities and to streamline market surveillance practices. This is also acknowledged by the European Commission and they announced to provide support to step up collaborations between all relevant actors

Finally, recommendations for policy makers have been posed:

1. Define criteria for sorting and recycling procedures.
   Sorting criteria to accomplish high quality input streams for recycling are under development and it is unclear to what extend the criteria are harmonized among different countries. Sometimes sorting can be done manually (for example by removing prints or removing outdoor gear) to limit presence of hazardous substances, but is important to consider if additional measures are necessary.
2. Increase knowledge on chemicals in (recycled) textiles.
   Only limited data are available regarding the presence of hazardous substances in recycled textiles. Policy makers can facilitate sharing of data and knowledge regarding chemicals in recycled textiles.
3. Develop tools for industry to assess legal compliance for recycled textile products.
   Product safety of recycled textiles requires the development of an analytical protocol for measuring specific substances in recycled textiles.
   It is advised to use the experiences from other industries to develop a guidance for monitoring the chemical quality of textile recycling.
4. Support 'design for recycling' and improve transparency on textile composition.
   Recyclability is important to realize a breakthrough of a circular textile economy, therefore design requirements (for easy disassembly) need to be developed and put into practice. For example, substances that hinder recycling technically as well as substances that are known to pose risks to consumers should be prevented from usage. Policy makers could support the development of open access knowledge platforms where information on chemicals in textile items can be shared between recyclers and product developers. Also, the development and implementation of digital product passports could improve transparency on textile composition (on fibre and chemical level) throughout the manufacturing chain.

1 Introduction

1.1 Context

The Dutch government aims to have established a circular economy by 2050. These objectives are set out in the "Rijksbrede programma Circulaire Economie" (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, 2016). This also applies to textile products such as (work) clothing and household textiles. The government has determined specific goals and actions for the textile industry, such as that steps are being taken with the textile sector to introduce Extended Producer Responsibility. This means that the producer remains responsible for the textile products they make, even if it is discarded and becomes waste.

The textile and clothing industry, considered at global level, has a large ecological footprint. The textile industry is one of the world's most polluting industries due to large use of water, energy and chemicals (Ministerie van Infrastructuur en Waterstaat, 2020b). Increased awareness has led to several initiatives within industry to improve the circularity of textile products. Several circularity strategies exist to reduce the consumption of natural resources and materials and minimise waste production, as well as rethinking the design of textile items, reuse of textile items (second hand) and recycling of textile. Initiatives and technologies for textile recycling are emerging rapidly and it is expected that recycled feedstock will form a significant part of future resources to be used.

A large variety of chemical substances is used in textile manufacturing and some chemicals can be harmful to human health and/or the environment. These chemical substances remain in the final product, intentionally or unintentionally. As a result, they may disturb subsequent processes, such as recycling processes. However, it is difficult to know exactly which substances remain in the textile and in the recycling process and in what concentrations.
Textiles that are collected today and enter a future recycling system have been placed on the market often several years before and may therefore have been produced prior to the enforcement date of current regulatory requirements.

Some of the chemical substances remaining in the textiles could reach the consumer, and a part of them is gradually washed out from the textiles during consumer use. Consequently, it is important to know what chemicals remain in the material before using them as feedstock in new products.

The successful recycling of textiles depends to a large degree on technical and economic aspects. But safety and compliance with chemical regulation is a prerequisite for achieving circular goals for textiles. Delivering recycled products to the market that are safe for consumers is also important for the societal acceptance of recycled textiles.

1.2 Research question and project methodology

To get more insight in the potential chemical risks to consumers of recycled textile products, the NVWA, the Netherlands Food and Product Consumer Safety Authority, has asked the RIVM to:

1. Provide an overview of recent developments in textile recycling
2. Describe potential risks for consumer safety with increasing recycling of textiles

To answer these two questions, we raised the following sub questions which have been answered in the report:

- What types of recycling process are already in place and which processes are under development? What happens with harmful substances during recycling? Can these be removed?
- What kind of textile fibres are suitable for recycling?
- For which applications can recycled textile fibres be used? It is important to know what will happen with hazardous chemicals when products/materials are used in new applications ('cycled'). This is particularly relevant if the new application is different from the original use. This might lead to new unintended exposure of consumers.
- Which goals have been set for the recycling of textiles? And what is the current situation?
- How has legislation with regard to chemicals in textiles changed over the last years and is that relevant related to the average use period of textiles?
- What is known about the presences of harmful substances in (recycled) textiles?

It is important to note here that this report is based on desk research. Analytical testing for the purposes of this report has not been conducted. The results of the report will primarily be used by the NVWA. However, the report could also be seen as input for further discussion between governments, businesses and other stakeholders.

This report focuses on recycling of raw textile materials and on associated (potential) human health effects, as well as on legal compliance. Environmental impact was not addressed in this report.

1.3 Reading guide

Chapter 2 describes the method and scope of the project. Chapter 3 provides an overview of the textile recycling chain and the different recycling technologies, whereas in chapter 4 an overview of policy programmes at EU and national level has been provided. An overview of legal frameworks for chemical substances and safety is described in chapter 5.
Chapter 6 summarizes available research on chemicals in both new and recycled textiles and describes the potentials chemical risks emerging from (increasing) recycling of textiles. This report ends with conclusions and recommendations in chapter 7.

2 Methods and scope

2.1 Scope

The aim of this project is to gain insight into the potential chemical risks of recycled textiles for consumers.

A number of substances are regulated on European level for their use in textiles because of potential health effects. If chemical substances are encountered in concentrations that exceed the legal limit values this can pose risks for consumers. The actual risk will depend on the toxicity of the substances and the level of exposure. Consumer exposure to substances used in textiles is mainly via the dermal route. One example of an health effect can be an allergic response (contact allergy). Another exposure route for textile chemicals is inhalation via textile dust or volatile substances in the air. Because of mouthing, children can also be exposed orally to substances in textiles.

For the purpose of this report, we have investigated if there is a risk that recycled textile products exceed legal concentration thresholds, or in other words, are in compliance with chemical legislation. When a concentration limit is exceeded, it does not necessarily mean that there is a (serious) risk. Concentration limits are not always quantitatively based on a specific effect of the substance (health-based), but are frequently general regulatory requirements. Even though the exceeding of a concentration limit is not always leading to a health risk, the exceeding is not desirable from the perspective of risk management and/or enforcement, since there are good reasons for the regulation of these substances.
Because of the focus on legal compliance, here substances are considered that are currently regulated or for which a restriction is being prepared. However, available data on the presence of non-regulated hazardous substances in recycled textiles are addressed too.

The focus of the report is primarily on products made of recycled materials that are intended for consumer use, such as clothing, furniture (i.e. upholstery) and household textile products (i.e. towels and bedlinen). More specifically, the focus is on products made from post-consumer textile, which is collected in textile recycle bins, rather than post-industrial textile. The latter is waste generated during textile manufacturing, such as cutting waste or excess fabrics. Recycling of post-production waste is expected to pose the same risks as newly manufactured textiles as this encompasses recycling of materials rather than finished goods. Also, the composition of the fabrics is known by the manufacturers and assumed to be compliant to existing regulations.

Beyond the scope of this project are technical textiles. Technical textiles are fibre-based products used in applications other than apparel and home furnishing. The main purpose of a technical textile is its functionality, not its aesthetics. These include, among others, medical textiles and textiles used in vehicles or construction (e.g. roofing).

Also, professional clothing is considered beyond the scope of this report because of the wide variety of materials and substances used. However, as such articles may end up in recycling streams, the consequences thereof will be addressed in the report. On the other hand, items that are not likely to end up in the same recycle streams as consumer products, such as carpeting or matrasses, are also considered beyond the scope.

With respect to recycling techniques, the emphasis will be on mechanical recycling, as this method is currently most widely in practice. Developments in other recycling techniques will be briefly addressed to provide some insight into recycling of consumer goods in the near future. As the goal of the project is to identify risks for the consumer when using articles with recycled content, emissions to the environment that occur during recycling (for example via waste water) are not within the scope of this project.

Textiles are made of a wide variety of fibres in which two main categories can be distinguished. The first category consists of textiles made from biological fibres, such as cotton, linen, bamboo or wool. The second category comprises of textiles made from synthetic fibres, among which are polyester, nylon and elastane. In the report, the focus will be mainly on textile fibres which are mostly used in consumer textile products, such are cotton, polyester or a blend of these two fibres (van Duijn, 2022). Other fibres will be discussed, in case information regarding chemical safety and recycling is available. This was the case for wool. Other materials exist which are being used in combination with textile fibres in for example furniture products, clothing or shoes. Leather, fur and down are examples of such materials. These materials will not be discussed in this report.

2.2 Methods

2.2.1 Desk study

For the description of the textile chain and recycling technologies, as provided in chapter 3, information was gathered via various means:

- Grey literature
- Consultation of textile experts
- European documents
- Scientific literature
- Company visits (CuRe, a chemical recycling facility for polyester; and Frankenhuis, a sorting and recycling facility for textiles)

To provide an overview of the circular economy policy context (chapter 4) and chemical policy and regulations (chapter 5), European and Dutch policy documents have been reviewed. All information relevant to the current report was taken into account.

A web search was performed to identify chemical substances that may be present in recycled textiles (in chapter 7) by using search terms such as such as "textile", "cotton", "textile recycling" and "chemicals of concern" and "hazard. Next to common web search engines, the search was carried out on websites of other European governmental institutes. Finally, the same search terms were applied in Pubmed and Web of

Science to select relevant literature. Additionally, internal newsletters of the last five years focussing on chemical risks have been reviewed to identify relevant literature for this study.
Regarding paragraph 7.4 on chemicals in recycled products, two reports with actual measurements of substances in post-consumer textile were available. The first was a study performed by the H&M and IKEA group in 2019 and the second study was performed by RISE (a Swedish state-owned research institute). Authors from the H&M/IKEA study were asked to share more information on the measurements performed, but this was currently not possible as the data are not publicly available at the moment.

2.2.2 Consultation of stakeholders

Stakeholders of the textile chain that currently use recycled fibres in their products, were consulted. They were asked, via a questionnaire or in an interview, to elaborate on their view on the challenges of textile recycling with respect to hazardous substances and current regulations. Additionally, producers were asked how they currently deal with hazardous substances and how they ensure for example compliance with REACH or other standards.

The following stakeholders in the textile chain were consulted:

- collector/sorter and recycler of post-consumer textiles (Wolkat)
- producer of jeans (Mud jeans)
- an initiative that develops circular fabric by forming different partnerships (Reblend)
- chemical recycler of cotton (SaXcell)
- chemical recycler of polyester (CuRe)
- mechanical recycler of post-consumer textiles (Frankenhuis)

The interview with stakeholders from Cure and Frankenhuis was combined with a company visit.

3 The textile chain

3.1 Introduction

Textile manufacturing is a complex process consisting of multiple steps. First, yarns are produced from natural (e.g., wool, cotton) or synthetic fibres (e.g., polyester). Secondly, textile fabrics can be produced by using technologies as weaving and knitting. Subsequently, these fabrics can be treated in order to obtain the required functionalities and characteristics. This may include dyeing, printing, coating, softening, water-proofing, fire-proofing and bleaching. Within these processing steps, the choice of substances is often fibre-specific.
Several initiatives and technologies for textile recycling are emerging rapidly. Figure 1 is a schematic overview of the current textile chain including production, use, and different end-of life options for collected consumer textiles in the Netherlands.
In chapter 3.2 the resources used for recycling processes are described. The use phase and what it means for chemicals in textiles is described in 3.3, followed by the sorting processes and the markets for reused and recycled textiles in chapter 3.4. The recycling processes will be discussed in more detail in chapter 3.5. Examples of products made from recycled fibres are listed in chapter 3.6.

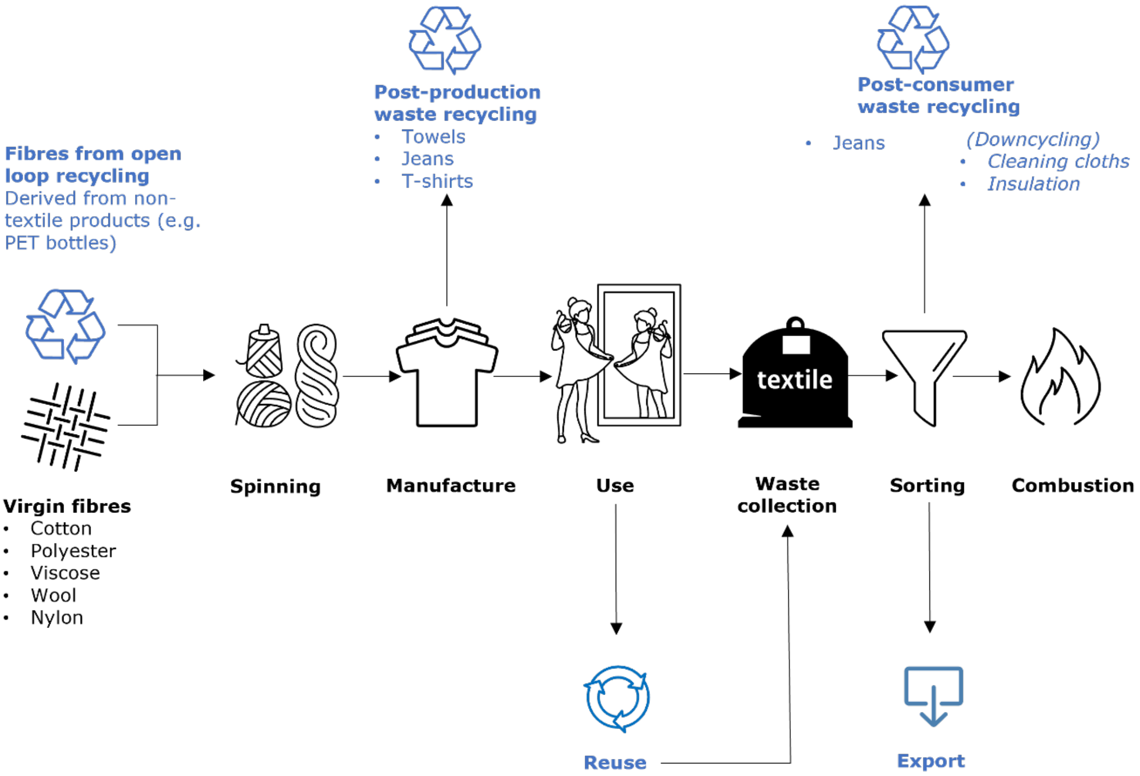

Figure 1 A schematic overview of the current textile chain including production, use, and different end-of life options for collected consumer textiles in the Netherlands.

3.2 Input materials for the recycling process

Secondary raw materials that are used as input for the recycling process can be divided in three categories: Post-production textiles (1), post-consumer textiles and recycled polyester (3). The amount of post-consumer textiles applied for the production of new textiles is currently much lower compared to the use of post-production textiles and recycled polyester.

1) Post-production waste is collected as fibres, yarns or fabrics (e.g., cutting waste), thus well before the garment is produced. These streams are often well-defined and more homogeneous. Post-production sources, therefore, have a much greater chance of achieving cost-effective, high-quality recycling than post-consumer streams, and some of these recycling methods are already implemented (Harmsen et al., 2021).
2) Post-consumer textiles are collected and sorted. Approximately half of the collected textile waste is suitable for the second-hand market (mostly abroad). Due to the rise of fast fashion (a manufacturing and marketing method focused on rapidly producing high volumes of clothing) and the decline of the second-hand market, the amount of textile suitable only for recycling (non-wearable fraction) increases every year (van der Wal & Verrips, 2019).
3) Resources for textile recycling may also come from outside the textile industry. Synthetic polyesters are used extensively in clothing and PET **(**Polyethylene terephthalate) is the most commonly produced form of synthetic polyester fibre. A process which is currently already implemented across the globe is the recycling of PET bottles into polyester fibres. PET bottles can be converted into textile fibres via a recycling process called extrusion. Contaminations may pose a problem in these kinds of processes, and this is therefore the reason that recycled fibres for textile products are often produced from transparent bottles (Harmsen et al., 2021). Post-consumer transparent bottles are relatively clean and result in a high-quality recycled PET, suitable for yarn production (Harmsen et al., 2021).

To prevent ”greenwashing” in the field of circular textiles, the NEN has decided to develop a certification scheme for the textile sector. This so-called ”Dutch Technical Agreement 8195” describes circular textiles and aims to be a standard for the Dutch circular textile industry. The definitions of circular textiles can be found in Annex 9.1.
Also can the NTA 8195 serve as a basis in the future for the development of a standardized reporting and assessment system and a validated standard test method for measuring circularity of textiles.

3.3 Use of clothing

In order to get a better understanding of the chemical composition of textiles that end up in a recycling facility, it is important to assess the lifespan of textiles. Chemical composition of textiles may have changed over the years, for example due to new regulations and substance restrictions. Hence, the article lifespan could in part determine the content of the recycled material with respect to the substances that are present. In general, it is difficult to assess the lifespan of textile articles as large differences between products may exist. At least for clothing, some data are available.

The climate action NGO WRAP has performed a consumer behaviour study with respect to the purchase, use and disposal of clothing items. A questionnaire was completed by consumers in Denmark, Germany, Italy and the Netherlands. Consumers were asked for a range of items they own, how long ago they acquired it, and how much longer they expect to continue wearing it. Based on these answers, the overall longevity of clothing was estimated to be 5.2 years in Denmark, 4.4 years in Germany, 4.1 years in The Netherlands and 3.5 years in Italy (WRAP, 2019). Additionally, longevity of clothing was associated with purchasing frequency. Anticipated longevity was lowest, varying from 2.9 to 4 years, among high frequent purchasers (people who purchase an item every fortnight) (WRAP, 2019).

Dutch consumers buy approximately 46 new clothing items annually and keep approximately 170 pieces of clothing in their personal wardrobe among which are about seven second-hand items (CREATE-IT (Amsterdam University of applied sciences), 2017). Each Dutch inhabitant throws away approximately 40 clothing items per year. Of these items, 25 are thrown away in general household waste. Five items are collected separately but they are not suitable for reuse, however they may be suitable for recycling. Two of these items are still wearable according to consumers, but not by international second-hand standards. Finally, nine of these garments are suitable for the international second-hand market (CREATE-IT (Amsterdam University of applied sciences), 2017).

In another study, in-depth interviews were conducted with 35 people from Norway on clothing items that were disposed of. The average lifespan of the garments was between five (males) and seven (females) years. The clothes that went out of use had been with the current owner on average for the past four years, showing that many of the clothes were reused. The total lifespan ranged from 0 to about 50 years (Laitala & Klepp, 2015).

One can assume that the textiles suitable for reuse may be somewhat more recently manufactured than textiles that are selected for recycling due to changing fashion trends. The age of post-consumer textiles that end up at mechanical recycling centres vary in age, but may be up to 30 years old (Frankenhuis, 2022) .

3.4 Collection and sorting of textiles

3.4.1 Description of collection and sorting processes

Currently in the Netherlands, post-consumer textiles, such as clothing, household textiles, and curtains, can be collected from ‘door to door’ or in clothing collection containers. A (post-consumer) textile sorting company can only collect these textiles in a municipality when it has been granted a textile collection permit in exchange for a fee (den Hartog et al., 2019).

Large textile collectors in the Netherlands are Leger des Heils, Curitas, Sympany and Boer Group. The collected textiles in municipalities are sorted in sorting centres. Dutch textile collectors either sort the post-consumer clothing themselves, sell the clothes to other stakeholders involved in the textile recycling chain or export the clothes to foreign sorting companies (Hopstaken et al., 2020). In addition, there are also collected textiles imported to the Netherlands from other countries (see chapter 3.4.2). The imported and exported streams of post-consumer textiles to and from the Netherlands are not sorted yet, however they have been cleaned from the non-textile components, for example the regular waste. In addition, the wet and dirty textiles have been removed from the textile streams (Hopstaken et al., 2020).

The higher quality textiles suitable for reuse are removed from the main post-consumer stream and the remainder of the textiles is separated by a variety of different methods in sorting centres. The methods enclose sorting by hand or by automatic techniques (See chapter 3.4.3). After sorting, a fraction of the downstream post-consumer textiles is recycled.

When an item is classified as non-rewearable, it is sorted for specific destinations, separately from the rewearables. Non-rewearables sorting is focused on identifying textiles fit for fibre-to-fibre recycling, chemical recycling (recent development), downcycling, or incineration (Frankenhuis, 2022).
Downcycling refers to recycling a material into a lower value product. Examples include recycling used garments into cleaning cloths and non-woven textiles (also known as felt) used as building insulation, or carpet underlay. The end-markets for non-rewearable textiles usually have lower prices than the rewearable textiles. More examples of products made from recycled fibres will be discussed in chapter 3.6.

3.4.2 *Import and export of textiles*

The Netherlands Environmental Assessment Agency (PBL) has researched the impacts related to cotton production and waste management for of a range of circular economy strategies for low and middle income countries (Brink et al., 2021). For that purpose, trade data on the current trade in cotton, clothing and post-consumer textiles to and from the Netherlands have been gathered. The data have been summarized in figure 2.

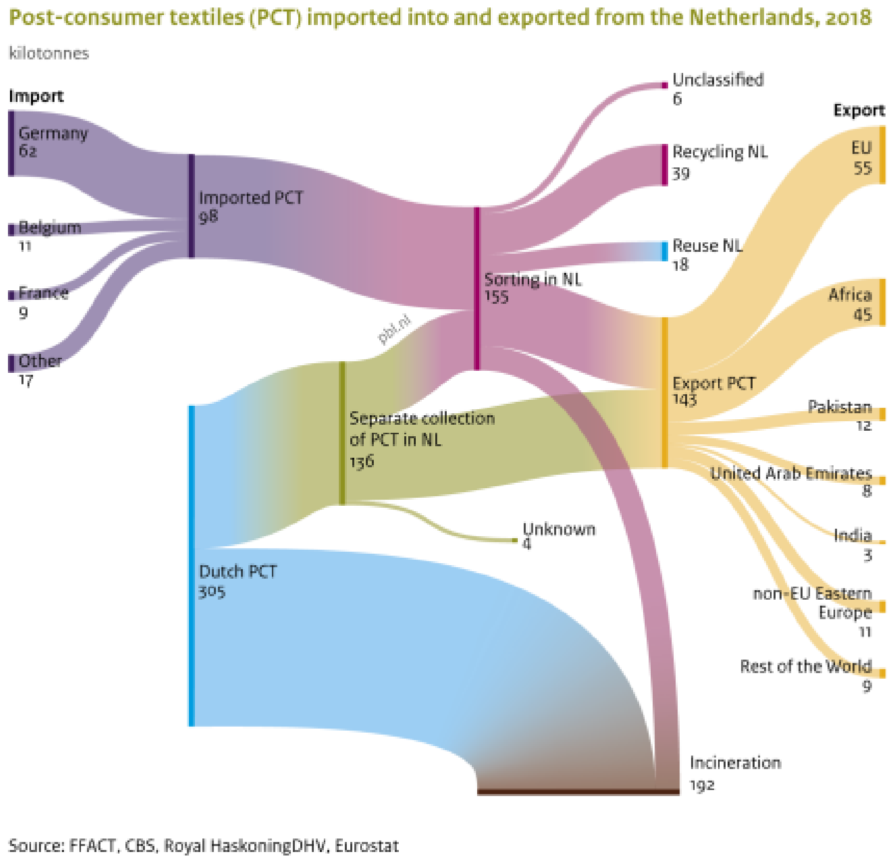

Figure 2 Post-consumer textiles imported into and exported from the Netherlands, 2018 (Brink et al., 2021)

The data available show that in 2018 around 305 kt of post-consumer textiles (clothing, footwear and linens) were discarded in the Netherlands. Around 55% of this amount ended up directly as municipal waste and, therefore, were incinerated. The remainder was collected. Since 2012, the total volume of post-consumer textiles has increased by around 20%, while the share that ends up in municipal waste remained more or less the same in 2018 versus 2012. In addition to domestically collected volumes, the Netherlands also imported around 98 kt of post-consumer textiles in 2018, mostly from neighbouring countries (Hopstaken et al., 2020).

Around 42% of the post-consumer textiles collected in the Netherlands are sorted domestically, together with the imported post-consumer textiles. More than half (55%) of the collected post-consumer textiles is directly exported and sorted abroad. Of the post-consumer textiles sorted domestically, around 12% is sold in the Netherlands, mostly through second-hand shops, 25% is recycled, for example into cleaning cloths (wipes) and fibre products (non-woven), and 15% is incinerated. The remainder is also exported abroad for reuse and recycling. Overall, around 48% of the total in post-consumer textiles in the Netherlands (domestic and imported) is incinerated, 35% is exported for reuse and recycling and 16% is reused or recycled domestically (Brink et al., 2021). Of the fractions suitable for recycling, 4% remains in the

Netherlands for the production of cleaning cloth or fibre products (Hopstaken et al., 2020).

While there are few data on what exactly happens with the exported Dutch post-consumer textiles, estimates show that around two thirds are eventually reused (mostly in Sub-Saharan Africa) and roughly one third is recycled (Brink et al., 2021). Regarding recycling, the South Asian countries (i.e., India and Pakistan) are important trading partners for further sorting, fibre processing and yarn manufacturing. Cleaning cloths and fibre products (felt/insulation material) are produced in Europe (Hopstaken et al., 2020).

3.4.3 Challenges in the sorting and recycling of textiles

The sorting process starts with pre-sorting where re-usable products (mainly clothes and shoes) are being separated from textile materials suitable for recycling. Garment recovery and reuse is an important component of the textile recycling industry. The sorting of textiles is a profession that requires specific knowledge of the sorting criteria and tactile skills. The reusable fraction is being sorted in categories based on quality, fashion trends, season and specific market demands and clothing categories such as shoes, trousers, sweaters. The sorting process is done manually and is therefore labour intensive.

The composition of the non-wearable fraction is not well-defined (Harmsen et al., 2021). Other sorting steps are required for the recycling of the non-wearable fractions. This involves sorting by colour as well as material and fibres.
The main challenge here is the difficulty to recover the fibres from textile products and to maintain the quality of the fibre. Blended textiles, containing different fibre types, create problems for textile recycling. Even cotton-rich materials like fitted sheets usually contain non-cotton materials (e.g. stitches or an elastic band) (Frankenhuis, 2022).

The high number of blends results in inadequately sorted textiles being used for generally more low-grade applications such as cleaning cloths and non-woven material (felt) applied as filling or insulation, than recovered for higher grade applications where such material could supplement the use of virgin fibre.

For the fibre-to-fibre recycling, the feedstock needs to be uniform in terms of structure of the fibre and fabric. Products composed of different materials cannot be recycled. Raincoats and jackets are examples of products which cannot be handled by recycling processes today. But also more simple products can have challenges. Fitted sheets contain elastane, which hinders both mechanical as chemical recycling processes. Products with labels, prints (e.g., T-shirts) and coating are not recycled at this moment either (Frankenhuis, 2022; Reblend, 2022; Wolkat, 2022). Before further processing, either the complete products or the prints have to be removed (cut out).
Denim is suitable as input for a mechanical fibre-to fibre recycling process. Zippers and buttons are removed during the process and the metal parts are sold for recycling. Fibre-to-fibre recycling (fiberizing) is applied by the company Frankenhuis for old jeans products. Products

that have been made from the old denim fibres are for instance, sound absorbing wallpaper and tents.

Frankenhuis is the single fiberizer of non-wearable (post-consumer) clothing in the Netherlands, and also in Europe, it is one of the few fiberizers on this level. The company is also actively looking for innovative applications of recycled fibres and to supply products to other recycling facilities (e.g., chemical recyclers).
Frankenhuis invested in a second production line, so the company can grow towards a production of around 15.000 to 20.000 tons per year. The dust filtering system is a closed system, and the recovered dust can partially be turned into paper (Frankenhuis, 2022).

The demand for post-consumer fibre is still low (van der Wal & Verrips, 2019). This is also confirmed by Frankenhuis. The majority of the output of the textile recycling processes results in applications outside the textile industry such as applications in the automotive and building sector (See chapter 3.6) (Frankenhuis, 2022).

The intricate blending of different types of fibres that requires different recycling strategies should be prevented. To be able to recycle, new design and material selection strategies that enhance the recyclability of their products are needed. Examples are fabrics based on one type of fibre, fibres with better recyclability profiles, and creating a market demand for recycled materials.
Designing textile products with recycling processes in mind can reduce labour costs and result in more material suitable for recycling. However, many fashion designers today are not aware yet about design-for-recycling guidelines. Additionally, the development of technologies to assist the disassembly and sorting process could reduce costs as well. Advanced sorting technologies such as the Fibersort[1] can sort textiles based on composition (e.g., wool, cotton, nylon, PET) and even colour, but can only process mono-materials as only the surface material can be identified. More technology development is required for a full identification of post-consumer textiles.

3.5 Introduction to recycling technologies

Textile recycling includes all processes on the level of fibres, polymers or monomers. Whether a garment is suitable for fibre, polymer or monomer recycling is determined in large part by the fibre composition and the chemical structure of the polymers that make up the fibres:

- Fibre recycling implies the preservation of the fibres after the disintegration of the fabric.
- Polymer recycling includes the disassembly of the fibres while the polymers remain intact.
- Monomer recycling implies that fibres and polymers are broken down into their chemical building blocks.

Each of these recycling methods requires (several) subsequent recycling methods to come to the desired product such as mechanical, physical and chemical methods (Harmsen et al., 2021).

[1] https://www.fibersort.com/

With respect to chemical recycling, three major technologies can be identified:

- Polymer recycling of cotton via a pulping process
- Monomer recycling of PA6 (polyamide 6, a type of nylon) or PET via (partial) degradation into oligomers or monomers
- Technologies focusing on the recovery of both cellulose and PET from polycotton blends. Due to the large differences between these technologies, they will be treated separately in the following sections.

3.5.1 Mechanical recycling

Description

Mechanical recycling is a process based on physical forces, and is an established technology in the market. It can be applied to wool and other natural fibres (cellulose-based such as cotton, jute, sisal, flax, etc.), and also synthetic fibres (polyester, polyamide, acryl, viscose, polypropylene, etc.).

During the mechanical recycling process, the fibres are recovered through processes of unravelling, grinding, defibrating and cutting.

The outputs of the mechanical recycling process are spinnable fibres, fluff, filling materials and dust. The fraction of spinnable fibres, which are fibres long enough to be respun into yarn, is 5-20% of the textile material input in case of natural fibres (e.g. cotton) and 25–55% of textile material input in case of polycotton or polyester (Duhoux et al., 2021). Mechanically recycled fibres can replace virgin cotton fibres, but need to be blended with virgin material to reach a yarn of an acceptable quality. As the fibres are shortened, weakened and damaged during the recycling process, their properties, functionality as well as quality deteriorate, making the supplement of new and high quality fibres necessary (Duhoux et al., 2021). Fibres from post-industrial textiles can be reused in new garments, i.e., in T-shirts and in hand towels (as pole yarn[2]). These products are made from 25-80% recycled fibres, in combination with virgin fibres. However, there are developments to increase the quality of mechanically post-consumer textiles by a better pre-sorting process (automatic sorting) and milder techniques to defibrate the fibres (Luiken, 2021).

The Dutch brand MUD Jeans states that they have been working intensively with their suppliers to find solutions to work with post-consumer cotton. The main obstacle is that with short fibres, it is difficult to create durable yarns and fabric. They produce jeans that contain between 23-40% post-consumer cotton. Their aim is to design jeans made of 100% recycled denim in the future (Mudjeans, 2022).

The remaining output fraction of the mechanical recycling process (fluff, filling materials and dust) has a lower quality than the spinnable fibre fraction and can be used in the non-woven industry, as a filling material or as reinforcement in composites of artificial material or incinerated (Duhoux et al., 2021). Another application of the dust mentioned by Frankenhuis is as resource for the paper industry (Frankenhuis, 2022).

[2] The yarn that makes the loops in the weave.

Fate of chemicals during mechanical recycling
Hazardous chemicals such as additives, dyes, finishes, etc. present in textile products (both through production and product use) cannot be removed in a mechanical recycling process and stay in the output. The remaining of colorants in the output fraction might be experienced as a disadvantage.

Chemicals used in the recycling process
According to research commissioned by the EU Commission (Duhoux et al., 2021), in the mechanical recycling process little or no chemicals are deployed. If chemicals are used, it concerns e.g. ozone, detergents, bleaching agents, organic solvents, etc. (Duhoux et al., 2021). According to Frankenhuis, no chemicals are used during fiberizing. According to Mud jeans anti-static agents can be used during the spinning process, the process that follows after fiberizing.

3.5.2 Thermomechanical recycling

Description
Thermo-mechanical recycling is a process using heat to melt synthetic (thermoplastic) textiles and recover the polymers in the form of regranulate (pellets) or fibres.
Theoretically, any thermoplastic fibre or textile, both pre-and post-consumer, can be reprocessed into a new fibre via thermo-mechanical recycling. Examples include polymers like PET, polypropylene (PP),PA6 and PA6,6 (two types of nylon). However, it is important that the input material consists of only one polymer type or of compatible polymer types. Incompatible polymers will not blend properly which will cause problems in processing, resulting in fibres of lower strength or even prevent fibre production altogether (Duhoux et al., 2021). For example, the presence of polyurethanes such as elastane can already complicate the recycling if they make up 0.5% of the blend.

Fate of chemicals during thermomechanical recycling
Chemicals may be released from polyester textiles during the recycling process. These chemicals are present in the input material as a result of treatment with dyes and pigments, prints, flame retardants, solvents, softeners etc. during textile production to enhance their properties (Duhoux et al., 2021). Thermal treatment in the thermomechanical and chemical recycling processes of polyester may release chlorinated organic compounds, silicones and alkylphenols through evaporation (Ostlund et al., 2015).

Contaminants can also hinder the spinning process and/or result in severely reduced output quality. For example, some products (like flame retardants) can cause hydrolysis of the polymer chain, resulting in reduced viscosity. Moreover, mixing of different coloured materials can lead to undesirable colours as dyes and pigments remain present. Hence, knowledge of the composition, type and amount of contamination and separation and sorting of the input material are extremely important (Duhoux et al., 2021).

Thermo-mechanical recyclers prefer production waste or large batches of known origin. Due to the high risk of contamination with other materials and/or hazardous chemicals, the heterogeneous and often unknown composition, clothing waste from households or fashion in general is not considered as a suitable input.

Chemicals used in the recycling process
Chemical’s consumption in thermo-mechanical recycling is low. According to an inventory commissioned by the European Commission, a technology holder claimed that, apart from the polyester input, no additional inputs are required in this process (Duhoux et al., 2021). It is assumed, however, that additional chemicals such as detergents and/or solvents may be involved during pre-treatment, since the polyester input needs to be of high purity and cleanliness not to perturb the melt-spinning process. Another technology holder reported only an antistatic chemical as an additional input for their process. According to Geyer et al. (2016) specific additives can be involved in thermomechanical recycling to improve viscosity and impact strength of recycled PET. These additives may include heat stabilizers, crosslinkers or chain extenders and compatibilizers (Duhoux et al., 2021; Geyer et al., 2016).

3.5.3 Chemical recycling of cotton

Description
Cellulosic fibres such as cotton can be chemically recycled via a pulping process. This process can be categorized as polymer recycling, as the cellulose chain is not broken down to monomer level (i.e., glucose), although it can be partially degraded.
The output consists of wet or semi-dried cellulose pulp that, depending on the technology, can be blended with wood pulp and processed in traditional spinning processes for man-made cellulosic fibres. There are various processes for spinning regenerated cellulose fibres of which the newer technologies (Lyocell, carbamate and ioncell) use more environmentally friendly and safer chemicals, often in closed-loop systems. These processes should be considered separately from the pulping process of cellulose textile waste because they are similar to the virgin regenerated cellulose fibre production. The pulping of the cellulosic textile waste is the actual recycling step (Duhoux et al., 2021).

Technology holders prefer textile waste with a cotton content of at least 50%, preferably as high as possible. Most processes could technically handle lower cotton levels, however this would not be economically feasible. Some technologies can separate PET from cotton, but most are still working on the recovery of PET and currently only the cotton fraction of blends can be recycled.
The tolerance to dyed textiles depends on the process, but most technologies include a decolouring and/or bleaching step, although with varying efficiencies. The colorant which is present in the material determines if bleaching is possible. The removal of any hard parts (buttons, zippers, etcetera) is required and can be done in the same way as for mechanical recycling. Most technology holders indicated that both pre-and post-consumer textile waste can be handled (Duhoux et al., 2021).

Fate of chemicals during chemical recycling of cotton
The pulping process often includes a chemical treatment. Dyes and finishes can be removed to some extent. The bleaching step is similar to the one in the traditional wood pulp production process.

Some technology holders implement an additional stage for the removal of polyester, elastane, etc. through several steps. Details on these steps are not available, since these are part of company IP (Duhoux et al., 2021).

Chemicals used during the recycling process
All types of pulping processes (polymer recycling) use a larger amount of chemicals compared to the mechanical recycling process. Typical chemicals used in a sulphur-free pulping process are hydrogen peroxide, sodium hydroxide and sulphuric acid. Sometimes ozone is used for bleaching and specific chemicals are applied for dye removal (Duhoux et al., 2021).

3.5.4 Chemical recycling of PET and PA6

Description
Both polyester and nylon fibres can be manufactured using chemical recycling processes. Chemical recycling implies a depolymerization step where the polymer chains are either broken down into oligomers or completely broken down into monomers. Monomer recycling costs more energy than breaking a polymer down to oligomers. The monomers or oligomers are separated and purified before entering the polymerization process again to produce new virgin-quality polymers. In theory many polymers can be depolymerized, but efficient, practical processes have not (yet) been developed, e.g., for PA6,6 a polymer with similar applications as PA6.

In theory any PA6 or PET textiles or plastics can serve as input.
- For PET: generally post-consumer food packaging materials and (pre-consumer) industrial waste, PET textiles recycling is still under development (CuRe, 2022; Roos S. et al., 2019).
- For Nylon (PA6): mainly post-consumer PA6 from carpets, also fishing nets and industrial waste (oligomers+ plastic waste generated by polymer industries) (Roos S. et al., 2019).

Fate of chemicals during chemical recycling
The main advantage of chemical recycling is that the recycled material can be purified and separated to obtain a pure, colourless polymer of good or even virgin-like quality.

Depending on the process, “light” contamination with other materials is allowed, generally dyes and prints and even certain finishes and coatings can be accepted (Duhoux et al., 2021). For nylon, there is a commercial chemical recycling process, and the process design is suitable for processing ‘contaminated’ materials, as the product exits at the top of the reactor and residues remain on the bottom (Harmsen et al., 2021).

With chemical recycling processes, the chemical substances present in the recycled textile products can be found in the solid residue or sludge waste output fraction, which indicates that the (hazardous) chemicals are removed during the recycling process (Duhoux et al., 2021). For example, in the purification step certain colourants can be removed using adsorption filters (CuRe, 2022). However, at the moment it is unclear whether all chemicals are removed with every chemical recycling process. Further research on the topic is needed.

One technology holder did stress that the nature of the contamination is also important as certain specific chemicals can have a large impact on the depolymerization reaction. Knowledge of the composition and adequate sorting of the input is thus of great importance.

Chemicals and PET/PA6 recycling
Chemicals used generally include a solvent (i.e., water in the case of enzymatic and hydrolytic processes, glycol for glycolysis and methanol for methanolysis), and one or more catalysts.

3.6 Products made from recycled fibres

In previous subchapters, the sorting procedures and recycling methods of post-consumer collected textiles were explained.

Here, the final applications of the recovered textile fibres are summarized. Table 1 lists examples of products resulting from current sorting and mechanical recycling processes. The data have been gathered by literature, web search and interviews. More examples of (Dutch) brands and products using post-consumer textile fibres can be found in the report "Handreiking circulair textiel voor verblijfsrecreatie" (Luiken, 2021).

Recycling of textiles is often a matter of downcycling where the recycled material is of lower functionality than the original material and recycling of fibres for similar applications is applied at limited scale.

Chemical recycling processes are still under development and have not yet reached commercial stage or market penetration on a large scale (Duhoux et al., 2021; Royal Haskoning DHV, 2021b). Therefore, this recycling method and its outputs are not considered in Table 1.

Table 1 Examples of products made from recycled textiles and recycled resources (e.g., PET bottles). Sources 1: Handreiking Circulair textiel (Luiken, 2021) 2. https://www.letsbehonest.eu// https://mudjeans.nl/ 3. Interviews with stakeholders (see chapter 2.1). 4. PBL report (Brink et al., 2021).

Recycled fibre type	**Product type**	**Sector**
Post-production recycled fibre (cotton)	T-shirts, polo's (1)	Apparel
	bed sheets (1)	Household textile
	hand towels (1)	Household textile
Fibre-to-fibre recycling (cotton)	jeans (1)((2)(3)	Apparel
	hand towels (1)	Household textile
	bed sheets (1)	Household textile
	upholstery (3)	Furniture and interior textiles
Bottle-to-fibre recycling (Polyester)	polyester products (such as fleece sweaters and sports shirts) (1)	Apparel
Recycling of textiles for other applications	insulating materials (3)(4)	Building sector, Household appliances (washing machines)
	Industrial (single-use) cleaning cloth (3)(4)	Professional use (several industries)
	carpet underlay (4)	Building sector
	parcel shelves (3)	Automotive
	stuffed toys (4)	Toys
	shoe insoles (4)	Shoes (apparel)

4 Circular economy policies and developments

4.1 Dutch policy program

Within the framework of the Government-wide Programme for a Circular Economy, launched in 2016, the Netherlands has described its ambition to move away from a linear economy and towards a circular system by 2050 (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, 2016). The overarching goals of this transition are to decrease and limit environmental pressures while addressing potential security of supply risks with regard to crucial resources.

In April 2020, the Netherlands formulated a policy programme for circular textiles 2020–2025 to support the transition towards a fully circular textile industry by 2050. The policy programme includes a set of policy targets for 2025, 2030 and 2035, which provide minimum standards for clothing sold on the Dutch market, concerning what they are made of (sustainably produced and secondary resources), what happens to them after being discarded (collection, reuse and recycling) and for their environmental impact (footprint) (Ministerie van Infrastructuur en Waterstaat, 2020a).
The goals for 2030 are displayed in the text box below.

2030 objective:
By 2030, we are half-way through the transition towards the circular economy, which means that:

- All textile products sold in the Netherlands contain 50% of sustainable material. Of that 50%, at least 30% is recyclate and no more than 20% is sustainable material.
- 50% of (raw) materials and products sold on the Dutch textile market are recycled after collection, if immediate reuse is no longer possible.

The first monitoring report on the policy programme concludes that much work needs to be done (Royal Haskoning DHV, 2021a) to reach this goal. For example, the share of recycled material in textile products is 1% in 2018 (Royal Haskoning DHV, 2021a). According to the second monitoring report, the share of recycled material increased from 1% to 4% in 2020 (Royal Haskoning DHV, 2021b).
The calculations are done based on data from Textile Exchange and SER-data and therefore the numbers are indicative. For determining more exactly the share of recycled content, a registration system with information about the composition of textiles brought to the market is required.

The government is set to introduce extended producer responsibility (EPR) rules for textiles by 2023. The new guidelines would mean the Dutch fashion sector will become responsible for the collecting and recycling of discarded clothing. The goal is to reduce textile waste and the use of virgin raw materials. Manufacturers will be responsible for the costs of the logistics of the system. Currently municipalities are responsible for the collecting and costs of managing end-of-life textiles from their residents. With the introduction of EPR, the manufacturers will pay for the waste management. The introduction of the EPR will enable policy makers and other stakeholders to keep track of the amount of textiles brought to market, and the share of collected, sorted, reused and recycled textiles.

4.2 Public-private initiative

The Denim Deal (Green Deal on Circular denim) is a public-private initiative, launched by the Dutch government. Signatories in the value chain (collectors, recyclers, producers, brands, retailers and public authorities) have jointly developed an approach to take major steps towards using recycled textile in all denim products marketed in the Netherlands. On April 2022, 44 signatories are committed to the Denim Deal, including more and more international brands. The signatories of the Denim Deal aim to close the denim loop by promoting the use of high-grade post-consumer recycled cotton fibres in new jeans and other denim garments (Ministerie van Infrastructuur en Waterstaat, 2022b).

This monitoring report provides the results of the quantitative 2020 baseline monitoring based on a monitoring form completed by all seven brands and retailers in the Denim Deal to report on the Denim Deal goals and results (Ffact, 2021). The results of the monitoring are summarized in the text box.

Monitoring results Denim deal for 2020 (Ffact, 2021):
Results denim garments (e.g. pants, dresses, skirts, jackets, shorts, shirts)
The results show that from the volume put on the Dutch market by the 7 participants, 8% contains at least 5% post-consumer cotton. And 12% of the volume of denim garments produced by the participants worldwide contains at least 5% post-consumer cotton. All seven brands and retailers aim to achieve a minimum of 5% post-consumer content in their own denim collections during the Denim Deal.
Most brands and retailers have set their own, more ambitious goals for post-consumer content in denim garments than the aimed new industry standard of 5%. Ambitious individual goals vary up from 10% – 20% to 80%, 90% and even 100% post-consumer cotton at the end of 2023.

Results jeans
The participating brands and retailers have placed in total 1,3 million jeans on the Dutch market in 2020. This is a relatively small part of the number of jeans placed on the Dutch market annually. From the volume placed on the Dutch market by participants, 105.033 jeans (8%) contain at least 20% post-consumer cotton. The results of the baseline measurement show for 2020 that 13% of the volume of jeans produced worldwide by participants contains at least 20% post-consumer cotton.

4.3 European textile strategy

The European Commission (EC) is addressing the challenges of the textiles sector as part of the European Green Deal and the Circular Economy Action Plan. The EC presented a new strategy in March 2022 to make textiles more durable, repairable, reusable, and recyclable:

the EU Strategy for Sustainable and Circular Textiles (European Commission, 2022). The strategy sets out the vision and concrete actions to ensure that by 2030 textile products placed on the EU market are long-lived and recyclable, made as much as possible of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment.
Moreover, consumers will benefit longer from high-quality textiles, "fast fashion" should be out of fashion, and economically profitable reuse and repair services should be widely available. The specific measures will include ecodesign requirements for textiles (see chapter 4.4), a Digital Product Passport and a mandatory EU extended producer responsibility scheme. In addition, the Strategy foresees measures to tackle the unintentional release of microplastics from textiles, to ensure the accuracy of green claims, and to boost circular business models, including reuse and repair services. To address fast fashion, the Strategy also calls on companies to reduce the number of collections per year, to take responsibility and act to minimise their carbon and environmental footprints. It also calls on Member States to adopt favourable taxation measures for the reuse and repair sector.

4.4 Ecodesign for Sustainable Products Regulation

The proposal of the European Commission for a Regulation on Ecodesign for Sustainable Products (ESPR)[3] establishes the framework for setting ecodesign requirements in several product categories, including textiles.

While textile products already are subject to certain requirements (use of chemicals, labelling), there are no specific requirements for circularity (durability, repairability, recyclability). The introduction of ESPR will set ecodesign performance requirements for textile products, information requirements, and a Digital Product Passport.

The proposed regulation provides a framework for the Commission to adopt Delegated Acts with specific requirements for a product or group of products. The Commission stated that it has preliminarily identified textiles, furniture, mattresses, tyres, detergents, paints, lubricants and intermediate products like iron, steel or aluminium as suitable candidates for the first ESPR Working Plan. In principle, each delegated act will provide:

- Performance requirements that products must comply with. These are in particular:
  Ecodesign requirements regarding durability; reliability; reusability; upgradability; repairability; possibility of maintenance and refurbishment; presence of substances of concern; energy use or energy efficiency; resource use or resource efficiency; recycled content; possibility of remanufacturing and recycling; possibility of recovery of materials; environmental impacts, including carbon and environmental footprint; and expected generation of waste materials.

[3] The EC proposal for Ecodesign for Sustainable Products Regulation (ESPR) was published on 30 March 2022, building upon the "Ecodesign Directive", which currently only covers energy-related products. The proposal for ecodesign (ESPR) is part of the Sustainable Products Initiative (SPI).

- Information requirements for all these sustainability aspects. Delegated Acts must include requirements that will enable the tracking of all substances of concern throughout the life cycle of products, unless such tracking is already enabled by another delegated act under the ESPR.

The Commission proposes to define substances of concern as substances that (a) meet the criteria for and have been identified as substances of very high concern (SVHC); (b) whose classification is harmonised under the CLP Regulation 1272/2008 regarding specific hazard classes; or (c) negatively affect the reuse and recycling of materials in the product in which it is present.

The Dutch government reacted upon the proposal of the European Commission stated (Ministerie van Infrastructuur en Waterstaat, 2022a). They stated to be positive about binding ecodesign requirements for textiles, product requirements for the minimalization of substances of very high concern in textiles and measurements to reduce microplastic pollution. The governments emphasized the application of circularity requirements and safe-and-sustainable-by-design at the beginning of the production chain.

4.5 Safe and sustainable by Design

Safe and Sustainable by Design (SSbD) is a holistic approach which includes focusing early in the supply chain on providing products that are part of circular models while avoiding properties that may be harmful to human health or the environment. It seeks to integrate "*safety, circularity, energy efficiency and functionality of chemicals, materials, products, and processes throughout their life cycle and minimize the environmental footprint*". The European Commission presented SsbD as a guiding principle in the regulation of the chemicals sector as part of the Green Deal policy initiatives, such as the EU Chemicals strategy for sustainability (European Commission, 2020).

The EU foresees the development of a framework to define SSbD criteria for chemicals and materials and plans the establishment of an EU-wide safe and sustainable-by-design support network.

The IRISS project is EU funded project launched in June 2022, which will build a network of stakeholders, including companies, researchers, authorities, and other societal actors and aims to connect, synergize and transform the Safe-and-Sustainable-by-Design (SSbD) community in Europe. IRISS will support companies, both with knowledge and through the implementation of research, and contribute to guiding principles for the development of life cycle thinking in material and product design. In collaboration with industry, a number of roadmaps will be developed to implement research and innovation, but also to demonstrate needs that exist in the policy area. One of the six value chains in the focus of the work is the textile industry.

4.6 Global initiatives

4.6.1 UNEP

The United Nations Environment Programme (UNEP) works on providing strategic leadership and encouraging sector-wide collaboration to accelerate a just transition towards a sustainable and circular textile value chain, while supporting sound management of chemicals.
Since January 2019, UNEP has been leading consultation workshops with stakeholders across the value chain to inform research and define priorities. The Report “Sustainability and Circularity in the Textile Value Chain - Global Stocktaking” was released in 2020 (United Nations Environment Programme, 2020) and identifies environmental and socio-economic impacts along the value chain, takes stock of initiatives working to address those, and outlines priority action areas.
UNEP is also leading programs to help with the management and reduction of hazardous chemicals in the textiles industry. An example is the project 'Reducing uses and releases of chemicals of concern in the textiles sector' which aims to eliminate the most harmful chemicals from the production processes in countries as Bangladesh, Indonesia, Pakistan and Vietnam.

4.6.2 Multi stakeholder initiatives

The Zero Discharge of Hazardous Chemical group (ZDHC) was started in 2011 as a coalition of 6 brands. Part of the initial work established a Joint Roadmap that demonstrated the collaborative efforts and steps needed to lead the apparel and footwear industry towards zero discharge of hazardous chemicals. In 2015, the ZDHC Joint Roadmap was updated and ZDHC transitioned to management under a legal entity established in the Netherlands – the ZDHC Foundation. The clearly established vision for the ZDHC Foundation is widespread implementation of sustainable chemistry, driving innovation and best practices in the industry to protect consumers, workers and the environment. Membership has grown from six brands in 2011 to approximately 160 today. The group is diverse and includes also brands from Europe.

In 2014, the ZDHC Manufacturing Restricted Substances List (ZDHC MRSL) version 1.0 was released. The MRSL differs from a RSL (Restricted substances list) because it restricts hazardous substances potentially used and discharged into the environment during manufacturing, not just those substances that could be present in finished products. The MRSL takes into consideration both process and functional chemicals used to make products, as well as chemicals used to clean equipment and facilities. Since 2014 guidelines and solutions have been created and implemented throughout the industry. The last update to version 3.0 was in November, 2022 and includes several new restrictions including on all PFAS used for textile, footwear, and leather treatments.

The ZDHC (M)RSL is among the most widely used list of restricted chemicals. RSL is a known tool in the textile industry, that can help textile companies and suppliers to be aware of the regulations concerning the prohibited amounts of substances in textiles. Some RSLs

may also take into account substances that are not legally restricted (yet), which can be regarded as a form of self-regulation.
Another well-known RSL is the AFIRM RSL (AFIRM group, 2022). AFIRM provides a testing matrix where a distinguishment is made between level 1 chemicals (minimum testing requirements) and level 2 chemicals (additional testing which may be required by specific brands). The AFIRM RSL also provides use information on the use of the substance and suitable test methods.

Brands can adhere to existing (M)RSLs such as ZDHC or AFIRM, or build their own (M)RSL starting from the standard (M)RSLs developed and maintained by bodies including Zero Discharge of Hazardous Chemicals (ZDHC), or the American Apparel and Footwear Association (AAFA).

5 Chemical policy and safety frameworks

For the Netherlands, the NVWA is charged with surveillance and enforcement of the safety of consumer products. To this end, the NVWA monitors (amongst others) compliance with the following Directives and Regulations:

- Regulation (EC) No 1907/2006 (REACH)
- Regulation (EC) No 528/2012 (Biocidal products)
- Regulation (EC) No 1007/2011 (Textile names)
- Regulation (EC) No 1272/2008 (CLP)
- Directive 2001/95/EC (General Product Safety Directive (GPSD))

In this chapter, the first three regulations will be discussed as these are most relevant for the recycling and safety of recycled products.

5.1 National regulation

5.1.1 Warenwet (Dutch legislation)

In addition to the European legislation, the Netherlands used to have two specific restrictions on the use/presence of formaldehyde and pentachlorophenol in textile producs. Up to April 2022, formaldehyde levels were limited to 120 ppm in clothing after the first washing. Pentachlorophenol was restricted in trade products, among which are textile products, in the Netherlands above 5 mg/kg since 1997[4] up to February 2016 (Dutch legislation; "Warenwet" accessed November 2022). Currently, new and stricter concentration limits have been established in the REACH regulation or POP regulation. Therefore, the restrictions in the Dutch legislation (Warenwet) have been withdrawn.

5.2 European Regulations

5.2.1 Textile Regulation

The European Regulation 1007/2011/EU on textile fibre names and labelling does not cover the use of (hazardous) substances. Under this Regulation, it is stated that the fibre content and composition of the textile product must be provided and printed on a label attached to the product. Additionally, non-textile products (e.g., leather) must be specified on the label as well.

5.2.2 POP regulation

Persistent organic pollutants (POPs) are substances that persist in the environment and pose a risk to the environment as well as to human health. POPs are characterized by stability, low water solubility, high lipophilicity, they are semi-volatile and have a high molecular weight. The POP regulation (EC 2019/1021) regulates such substances by prohibiting them, phasing the POPs out as soon as possible or restricting the production. POPs that are regulated and pose a risk of being used in, or contaminate, textile material are listed below.

[4] https://zoek.officielebekendmakingen.nl/stb-1997-471.html

Table 2 Overview of chemical substances relevant for the textile industry regulated by POP regulation (ECHA, 2023).

Substance	**Restriction**	**Year the substance was regulated as POP**	**Use of the substance in a textile product**
Chlorinated pesticides and insecticides are banned. This group contains the following substances: aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, hexachlorocyclohexanes, chlordecone	Ban for production and use.	2004	Pesticides and insecticides
DDT ((1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane)	Restriction	2004[5]	Pesticides and insecticides (e.g. moth protection in woollen blankets)
Pentachlorobenzene	Ban for production and use.	2010	Pesticides and insecticides
Pentachlorophenol	Ban for production and use.	2019	Pesticides and insecticides (e.g. in cotton tents)
Hexabromocyclododecane (HBCDD)	0.01% by weight	2016	Flame retardant
DecaBDE	0.001% by weight	2019	Flame retardant
Perfluorooctane sulfonic acide and its derivatives (PFOS)	1 µg/m^2 of the coated material in textiles.	2010[6]	Water, oil, stain repellent.
Perfluoroctanoic acid (PFOA), its salts and PFOA-related compounds	≤ 0.025 mg/kg for PFOA and any of its salts ≤ 1 mg/kg for each PFOA-related compound and a combination of PFOA-related compounds	2020, however allowed in textiles for worker protection for dangerous liquids Until July 4, 2023	Water, oil, stain repellant

5.2.3 *REACH Regulation*

The REACH regulation (EU No. 1907/2006) covers the Registration, Evaluation, Authorisation and Restriction of Chemicals in Europe. REACH obliges companies to register and provide safety data on all substances produced or imported in the EU in quantities greater than 1 ton per year. This registration should include the substance's use in articles when relevant. For substances imported or produced above 10 tonnes per year, chemical safety assessment has to be carried out to demonstrate that the risks from the exposure to a substance, during its

[5] DDT is banned in the Netherlands since 1973.
[6] PFOS was originally included in REACH annex xvii restricted substances list

manufacture and use, are controlled when specific operational conditions and risk management measures are applied.

For certain substances with specific toxicological properties, substitution is preferred and the authorisation of the use is required when substitution is not feasible. Substances with hazard properties that meet the criteria for classification as being carcinogenic, mutagenic or reproduction toxic (1A or 1B, according to CLP), or persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) according to REACH Annex XIII or with an equivalent concern (REACH article 57f) can be identified as substances of very high concern (SVHCs). SVHC substances are then placed on the Candidate list of SVHCs for authorisation. Once a substance has been added to the candidate list, there is a requirement to communicate information on any presence of the substance above a concentration of 0.1% in articles, including textile articles. This notification is also required for imported articles. If given a high priority, substances on the candidate list can be placed on Annex XIV of REACH and, as a result, these substances may only be applied in authorised uses.

Another route to regulate substances is via restrictions (Annex XVII of REACH). Restrictions are normally used to limit or ban the manufacture, placing on the market, or use of a substance. It permits risk management beyond measurements that are already implemented. A list of substances that are restricted for use in textiles under REACH is provided in Table 3 as well as a list of substances which are generally restricted for their use in articles with a known use in textiles.

Table 3 Overview of chemical substances relevant for the textile industry currently regulated by REACH in Annex XVII, with the former legal framework provided, when relevant.

Substance	**Restriction**	**CAS nr.**	**Concen-tration limit**	**Year the restriction is in force**	**REACH entry**	**Use of the substance (AFIRM group, 2022)**
Tris (2,3 dibromopropyl) phosphate	Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin.	126-72-7	NA	1979 (79/663/EEC)*	Entry 4	Used as a flame retardant in synthetic fibres. The substance was last being sold in the late 1970s (RISE IVF et al., 2019)
Tris(aziridinyl) phosphinoxide	Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin.	545-55-1	NA	1983 (83/264/EEC)*	Entry 7	Flame retardant in textiles.
Polybromobiphenyls; Polybrominated biphenyls (PBB)	Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin.	Multiple	NA	1983 (83/264/EEC)*	Entry 8	Flame retardant in textiles.
Mercury compounds	Shall not be used in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture.	Multiple	NA	1989 (89/677/EEC)*	Entry 18	Can be present in pesticides, as contaminant in NaOH, or in paints/catalysts used for PVC manufacturing.
Tri-substituted organostannic compounds such as tributyltin and triphenyltin.	Shall not be used in articles. (general restriction in articles, not specific to textiles)	Multiple	0.1% by weight of tin	2010	Entry 20	Biocides and catalysts in plastic production. In textiles presence is associated among others with plastic components, paints and glitter.

Substance	Restriction	CAS nr.	Concen-tration limit	Year the restriction is in force	REACH entry	Use of the substance (AFIRM group, 2022)
Dibutyltin compounds	Shall not be used in mixtures and articles for supply to the general public. (general restriction in articles, not specific to textiles)	Multiple	0.1% by weight of tin	2012	Entry 20	Biocides and catalysts in plastic production. In textiles presence is associated among others with plastic components, paints and glitter.
Dioctyltin compounds	Shall not be used in textile articles intended to come into contact with the skin, gloves, footwear or part of footwear intended to come into contact with the skin.	Multiple	0.1% by weight of tin	2012	Entry 20	Biocides and catalysts in plastic production. In textiles presence is associated among others with plastic components, paints and glitter.
Cadmium and its compounds	Shall not be used in mixtures and articles produced from synthetic organic polymers such as PVC, PUR, PET, PP, etc.	7440-43-9	0.01% by weight of the plastic material	1991 (91/338/EEC)*	Entry 23	Component of pigments/paints used in textiles, stabiliser for PVC, biocides.
Azocolourants and azodyes that may release aromatic amines.	Azodyes which, by reductive cleavage of one or more azo groups, may release one or more of the aromatic amines listed in Appendix 8 of REACH, in detectable concentrations, i.e. above 30 mg/kg (0,003 % by weight) in the articles or in the dyed parts thereof, shall not be used, in textile and leather articles which may come into direct and prolonged contact with the human skin or oral cavity.	Multiple	30 mg/kg (0,003 % by weight) or 0.1% by weight.	2004* (2004/21/EC) It is noted that some measures were already in force before 2004 and that amendments were made after 2004.	Entry 43	Textile dyes.

Substance	Restriction	CAS nr.	Concen-tration limit	Year the restriction is in force	REACH entry	Use of the substance (AFIRM group, 2022)
	Azodyes, which are contained in Appendix 9 of REACH, 'List of azodyes' shall not be placed on the market, or used, as substances, or in mixtures in concentrations greater than 0,1 % by weight, where the substance or the mixture is intended for colouring textile and leather articles.					
Nonylphenol and Nonylphenol ethoxylates	Shall not be placed on the market, or used, as substance or in mixtures for the purpose of textiles and leather processing except in processing with no release into waste water and systems with special treatment where the process water is pre-treated to remove the organic fraction completely prior to biological waste water treatment (degreasing of sheepskin).	Nonylphenol: 25154-52-3 Nonylphenoletoxylates: multiple	0.1 % by weight	2009	Entry 46	Scouring agent for wool (degreasing). Washing and cleaning agents, spinning oils in textile manufacture. Dispersing and emulsifying agents in textile chemicals as well as impregnation agents in printing pastes.
Nonylphenol ethoxylates[7]	Restricted in textile articles that are expected to be washed in water. equal to or greater than 0,01 % by weight of that textile article or of each part of the textile article This does not apply to second hand articles or articles produced, without		0.01% by weight	2016 (effective from February 2021)	Entry 46a	Scouring agent for wool (degreasing). Washing and cleaning agents, spinning oils in textile manufacture. Dispersing and emulsifying agents in textile chemicals as well

[7] Nonylphenol ethoxylates (NPE) $(C_2H_4O)_nC_{15}H_{24}O$

Substance	Restriction	CAS nr.	Concen-tration limit	Year the restriction is in force	REACH entry	Use of the substance (AFIRM group, 2022)
	the use of NPE, exclusively from recycled textiles. *"textile article" means any unfinished, semi-finished or finished product which is composed of at least 80 % textile fibres by weight, or any other product that contains a part which is composed of at least 80 % textile fibres by weight, including products such as clothing, accessories, interior textiles, fibres, yarn, fabrics and knitted panels					as impregnation agents in printing pastes.
Polycyclic aromatic hydrocarbons (PAHs)[8]	Articles shall not be placed on the market for supply to the general public, if any of their rubber or plastic components that come into direct as well as prolonged or short-term repetitive contact with the human skin or the oral cavity, under normal or reasonably foreseeable conditions of use, contain more than 1 mg/kg (0,0001 % by weight of this component) of any of the listed PAHs. Such articles include amongst others: clothing, footwear gloves and sportswear.	Multiple	1 mg/kg (0.0001 % by weight)	2013 (transitional period until 2015)	Entry 50	Contamination of carbon black, dyes or other petrochemical products. Can be present in rubber components. PAHs are often found in the outsoles of footwear and in printing pastes for screen prints. PAHs may be formed from thermal decomposition of recycled materials during reprocessing

[8] Benzo(a)pyrene, benzo(e)pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, dibenzo(a, h)anthracene.

Substance	Restriction	CAS nr.	Concen-tration limit	Year the restriction is in force	REACH entry	Use of the substance (AFIRM group, 2022)
C9-C14 linear and/or branched perfluorocarboxylic acids (C9-C14 PFCAs), their salts and C9-C14 PFCAs-related substances	Shall not be used in, or placed on the market in another substance as a constituent, a mixture or an article. This applies to textiles for oil- and water-repellency for the protection of workers from dangerous liquids that comprise risks to their health and safety;	Multiple	25 ppb for the sum of C9-C14 PFCAs and their salts or 260 ppb for the sum of C9-C14 PFCA-related substances	2023	Entry 68	Water repellent coating of textiles.
CMR substances (listed in column 1 of the Table in Appendix 12 of the REACH regulation; which is provided in the Annex 9.2). Among these substances is formaldehyde.	Shall not be placed on the market in any of the following: (a) clothing or related accessories; (b) textiles other than clothing which, under normal or reasonably foreseeable conditions of use, come into contact with human skin to an extent similar to clothing. The restriction does not apply to second-hand clothing, related accessories, textiles other than clothing or footwear as well as wall-to-wall carpets and textile floor coverings for indoor use, rugs and runners.	Multiple	Specified for CMR substances in Appendix 12 of REACH. Formaldehyde: 75 mg/kg	2020 2023 (for Formaldehyde)	Entry 72	Amongst others: Formaldehyde: anti-creasing and anti-shrinking of textiles. Quinoline: found as an impurity in polyester and some dyestuffs. Chlorotoluenes can be used as carriers in the dyeing process of polyester or wool/ polyester fibres. They can also be used as solvents.

Substance	Restriction	CAS nr.	Concen-tration limit	Year the restriction is in force	REACH entry	Use of the substance (AFIRM group, 2022)
Phthalates[9]	Shall not be placed on the market in articles, individually or in any combination of the phthalates listed in column 1 of this entry (see footnote 9).	Multiple	0.1 % by weight of the plasticised material	2020	Entry 51	Used in PVC prints on textiles. Adhesives, flexible plastic components.
Dimethyl fumarate	General restriction in articles, not specific for textiles.		0.1 mg/kg	2012	Entry 61	Anti-mold agent used during shipping and storage, especially in leather and textile furniture.

* Some restrictions were already in place in legislations that were in place before REACH. Generally, a derogation period of maximum one year was in place after the restrictions came into force.

[9] Bis (2-ethylhexyl) phthalate (DEHP), Dibutyl phthalate (DBP), Benzyl butyl phthalate (BBP), Diisobutyl phthalate (DIBP)

5.3 Future perspectives on REACH legislation

A number of restrictions under REACH on the production and use of textile chemicals and textile auxiliaries could arise in the short and medium term. In this chapter we discuss two proposed restrictions which are foreseen to apply to textile products.

5.3.1 Skin sensitizers

The EU Member States France and Sweden proposed a restriction for skin sensitising, irritative or corrosive substances in textile and leather articles under REACH (Member State France and Sweden, 2019). In 2020, this restriction dossier has been evaluated by RAC and SEAC and now the restriction conditions have to be adopted by the European Commission in order to be taken up in the REACH Regulation.
The full restriction conditions proposed can be found in Annex 9.3. Briefly, it is proposed to prohibit substances with a harmonised classification as skin sensitisers in Category 1, 1A or 1B, as well as an additional list of substances of concern, in clothing or other textiles articles that come into contact with the skin (e.g. household textiles or carpets). It is noted that both RAC and SEAC did not agree on the inclusion of some of these additional substances listed.
Clothing and textile articles may not contain substances that belong to the group with disperse dyes with a harmonized classification as skin sensitisers. For the other compounds, the following concentration limits are proposed by RAC and SEAC:

- 1 mg/kg for extractable chromium VI compounds;
- 30 mg/kg for formaldehyde (RAC proposal)/ 75 mg/kg for formaldehyde (SEAC proposal)
- 125 mg/kg for nickel and its compounds;
- 70 mg/kg for cobalt and its compounds;
- 250 mg/kg for 1,4-paraphenylenediamine;
- 130 mg/kg for other substances classified as skin sensitisers category 1, 1A or 1B.

It is noted that a final decision about the restriction and concentration limits still needs to be taken. Other concentration limits are proposed for these compounds in articles made of leather, fur and hides. The restriction does not apply to substances that are used as active ingredients in biocidal products. Additionally, the restriction does not apply to textile articles used as personal protective equipment or medical devices nor does it apply to second-hand clothing.

5.3.2 PFAS

Perfluorinated and polyfluorinated alkyl compounds (PFAS) are a large group of synthetic chemicals. PFAS are used in textiles to obtain water, dirt and/or oil repellence. Its applications are outdoor textiles, personal protective equipment and home textiles and apparel.

From a regulatory perspective, most of the attention has been placed on the two most common types: perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), both long-chain PFAS with C8 chemistry (8 carbons in the chain). Both substances are restricted under the POP regulation. PFOS was originally included in REACH annex xvii restricted substances list.[10] PFOS is now regulated as a persistent organic pollutant (POP) in EU. Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds have been banned under the POPs Regulation since 4 July 2020.

Due to these restrictions, many textile manufacturers switched to short-chain substances like PFHxA (C6) instead[11]. However, evidence shows that these substances are also very persistent and mobile in the environment and can damage the human reproductive system. The PFHxA are now being considered for restriction. Both scientific committees RAC and SEAC support the restriction in their opinion. The final decision by the European Commission and Member States still needs to be taken.

Considering the risks related to all substances of the PFAS group, the European Commission is committed to their gradual elimination. Several Member States have started to work on developing a broad restriction proposal under the REACH Regulation (submitted in January 2023). This would in the long run mean phasing out of all PFAS in non-essential uses. The timing of the approval of the proposed restriction on PFHxA (C6) will influence how quick this transition to PFAS-free textiles for consumers will take place.

5.4 Biocidal Products Regulation

The Biocidal Product Regulation (BPR) (EC, 2012) concerns the placing on the market and use of biocidal products intended to protect humans, animals, materials or articles against harmful organisms by the action of active substances contained in the biocidal product. Biocides can be applied to textiles with a specific intention, such as to serve an antibacterial function or as an insect repellent. Their uses are diverse and range from repelling moths in wool carpets, to preventing the growth of odour-causing bacteria in textiles. Biocides can also be used to protect clothing against damage by microorganisms (mainly fungi) and insects during storage and transport.

The BPR distinguishes four groups of products: disinfectants, preservatives, pest control and other biocidal products. Within these groups a number of product types (PTs) are defined. Among the first three groups are product types with potential relevance for textiles:

- disinfectants and algaecides not intended for direct application to humans or animals (PT2)
  such as textiles with an antibacterial hygienic function intended, for example, to inhibit the growth of pathogens or prevent disagreeable odours
- preservatives for products during storage (PT6)
- fibre, leather, rubber and polymerised materials preservatives (PT9)
  such as carpeting treated with insecticides against moth damage

[10] After PFOS was added to the Annex B of the Stockholm Convention in 2009, the European Commission removed PFOS from REACH annex xvii and added it to the annex I of the Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants.
[11] https://echa.europa.eu/nl/-/scientific-committees-support-further-restrictions-of-pfas

- insecticides, acaricides and products to control other arthropods (PT18)
  such as mosquito nets treated with insecticides to kill insects
- repellents and attractants (PT19)
  such as sleeping bags treated with repellents to repel insects

Under the BPR these types of specific use require authorization, including a risk assessment indicating safe use and information on whether any possible risks to consumers have already been sufficiently controlled. The national authorization of biocides is a task performed by the Competent Authorities of individual Member States. In the Netherlands, the Board for the Authorisation of Plant Protection Products and Biocides (Ctgb) is responsible for this task. To avoid duplication of the evaluation procedure, the product authorisation granted in one Member State can be recognised in other Member State through the mutual recognition procedure. Under the BPR a union list is established of active substances approved for use in specific PTs.

Some substance with a biocidal activity are restricted under the REACH Regulation or POP regulation. This applies, for example, to dimethyl fumarate (DMF; restricted in articles) and pentachlorophenol (PCP; ban on manufacture and use).

5.5 Voluntary initiatives: labels and certifications

Several voluntary initiatives in the form of textile labelling schemes exist which serve as guides for consumers and industry. For textiles, there are several ecolabels involving certification of industrial companies that meet these labels' criteria. Among the criteria are often lists of substances with concentration limits that must not be exceeded. Below is an overview of the most common labels with substances lists in place based on a report from ANSES and the available overview on the Dutch website Waarzitwatin (ANSES, 2018; Waarzitwatin, accessed 1 dec. 2022):

- Global Organic Textile Standard (GOTS); a worldwide standard aiming to guarantee that textile clothing items are produced in an organic way.
- Nordic Swan Eco-Label; a Scandinavian label with strict environmental requirements and requirements for the use of chemicals during the whole product life cycle.
- EU Ecolabel; this label guarantees a sustainable production of textile fibres, a less polluting production process and restrictions on the use of hazardous substances. The ecological criteria for the award of the EU Ecolabel for textile products is established by law (2014/350/EU).
- OEKO-TEX Standard 100; a global health label for textile raw materials and finished products. The OEKO-TEX standard has requirements for the presence of hazardous substances. For example, the textile is tested for the presence of prohibited dyes and colourants, carcinogenic substances, allergenic substances and heavy metals. Products with recycled materials can also be certified with the OEKO-TEX standard 100. Different rules for certification apply. For example, a minimum of 20% of the content has to be recycled material, information on the source

material has to be provided, and a different testing program (i.e. a higher testing frequency) compared to virgin materials may apply. Articles containing recycled materials from post-consumer sources are excluded for applying for certification according to class I, the class with strictest limit values.

- Cradle to Cradle Certified™ Product Standard; a standard which deals with five aspects of a product to guide designers and manufacturers for continuous improvement: Material heath, material reutilization, renewable energy and carbon management, water stewardship and social fairness. The product composition and production process undergoes an assessment by a certified organization and receives a level in each category- basic, bronze, silver, gold or platinum.
- Bluesign; a Swiss certificate focusing on sustainable manufacturing of textiles with emphasis on the chemicals that have been used in the production process and in the article itself.

6 Regulatory barriers for textile recycling

6.1 Textile Regulation (EU) No 1007/2011

Producers of recycled textiles, may experience difficulties with respect to conformity to the Regulation (EC) No 1007/2011. The fact that this is identified as a barrier has been described in the report "Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling" commissioned by the European commission (Duhoux et al., 2021)". It is summarized in this chapter.

In the mechanical recycling process, it is difficult to maintain a stable output when the input is not fully under control (Duhoux et al., 2021). With fully under control is meant that the complete history of the textile is known, including production and use. E.g., a batch of garments made of polyester and cotton fibres that are intimately blended will be irregular in composition depending on the fibre loss during use. So, despite the same composition of all pieces, the use can lead to a different composition for every piece. Additionally, it is possible that fibre material from previous recycled textile stays behind in the recycling equipment and will contaminate future production batches. This all leads to an irregular output of materials. According to Duhoux et al. (2021), the fibre content can, therefore, differ within one batch.
In this regard, article 9 paragraph 4 of Regulation (EU) n° 1007/2011 states that without prejudice to article 5(1), for textile products the composition of which is hard to state at the time of their manufacture, the term "mixed fibres" or the term "unspecified textile composition" may be used on the label or marking. A manufacturer can declare that the textile product contains "mixed fibres" or "unspecified textile composition", however this would influence the provision of precise information on the fibre content to the consumer. A fibre composition declaration of a textile product made of virgin fibres and recycled fibres may identify the latter as mixed fibres. This might alert market surveillance authorities in case of compliance checks with Regulation (EU) n° 1007/2011 to conclude that the product is not compliant because the declaration of fibre content would exceed the manufacturing tolerance of 3% established in article 20 paragraph 3 of Regulation (EU) n° 1007/2011. Therefore, it is important that the textile fibre content declaration provides clear information about the textile recycled content so that market surveillance authorities, which check the conformity with Regulation (EU) n° 1007/2011, can take these deviations into account.

For the purpose of sorting and recycling textile waste, however, there are additional shortcomings, specifically regarding the usefulness of the textile labels:

- Information on the labels is not sufficiently specific for certain recycling processes. For example, the labels do not differentiate between different types of nylon – yet this information is crucial for certain recycling processes.
- Labels in discarded textile products are often missing or washed-out. This disrupts not the flow of information for recycling.

- Information on chemicals used during production process is missing.

Based on the research (literature analysis, expert interviews combined with a survey) by Duhoux et al. (2021), it was found that the most important information needs for textile recyclers are:

1) more detailed data on fibre content
2) data on chemical content

In addition, many study respondents considered information on the use of recycled fibres, information on accessories and information on design for recyclability to be important to enable recycling.

6.2 Presence of legacy substances in post-consumer textiles

A product that was placed on the market years ago might not automatically be compliant with the regulations of today, because several chemical substances have been included in the Candidate List of "Substances of Very High Concern" (SVHC)-list, have become the object of restriction or are subjected to authorisation. As dyes, finishes, and other additives are not (completely) removed during mechanical recycling, it is possible that some recycled materials contain chemicals that are no longer allowed according to the REACH-regulation or POP regulation.
Due to practical reasons it is hard to check the fibre content of every product that goes into the process (fibre contents might have changed during use, labels are removed) and it is too costly and time-consuming to test every product. According to personal communication with textiles recyclers and brands using recycled textile fibres, it was confirmed that at least in some cases testing is being performed to verify the presence of SVHC substances (Reblend, 2022; Wolkat, 2022). However no defined standard or procedure which defines the sampling process, testing procedure and frequency was identified for this purpose.

Furthermore, very high volumes of articles are imported into Europe each year posing a challenge for surveillance authorities. Ensuring compliance of imported articles is challenging also with respect to the increasing number of restrictions and the increasing amounts of substances per restriction.

Nowadays, also consumers themselves can directly buy clothing or other textile items from web shops situated outside Europe. The increasing share of imported goods by individual consumers via online shops could lead to the situation that textile products containing chemical substances that are banned in Europe will ultimately end up in textile collection in the Netherlands. It may be the case that such articles do not meet the safety requirements as laid down in European legislation (Aalbers & ten Grotenhuis, 2020). This is the case when products are being sold that are not intended for the European market. When products are imported directly, via online platforms, importers and distributers (which are responsible for legal compliance) are missing. Some online platforms have signed a Product Safety Pledge, and committed voluntarily to avoid unsafe products (Aalbers & ten Grotenhuis, 2020).

7 Chemical substances in textile products

7.1 Chemicals used in textile manufacturing

Textile manufacturing is a complex process consisting of multiple steps. First, fibres are produced from natural (e.g. wool, cotton) or synthetic fibres (e.g. polyester). Most of the textile products today are made of mixed materials. The fibres are spun into yarns, which are in most cases processed by knitting or weaving into textile fabrics. The fabrics can also go through pre-treatment, dyeing and printing, and finishing processes. In the finishing process, the fabrics can be treated in order to obtain the required functionalities and characteristics. This may include coating, softening, water-proofing, or fire-proofing. Within these processing steps, the choice of substances is fibre-specific.

The life cycle of textiles comprises many different stages. The steps in textile processing are:

1) Fibre production
2) Yarn production
3) Fabric production
4) Pre-treatment
5) Dyeing/printing
6) Finishing

Table 9 in Annex 9.4 lists the different processing steps and chemicals involved in each step. Chemicals of concern have been used or can be used throughout the production process, from fibre production to finishing. It should be noted that the Table includes chemicals banned (and expected to be banned) by the REACH regulation. For chemicals of concern that are not (yet) banned, multiple collaborative mechanisms for self-regulation have emerged, such as shared guidelines and certifications. Brands are increasingly adopting (M)RSLs as the foundation of their chemical management policy.

7.2 The use phase of textiles and fate of chemicals

One of the issues with recycling is the limited control of the input material. In part this is due to the user phase in which consumers for example wash their clothing or treat textile products with chemicals.

7.2.1 Washing

Some substances can be washed out of the textile during the washing of clothes in a household wash. It is for example recommended to wash new clothes to get rid of the excess amount of colourants or formaldehyde which can still be present in the new product. In general, substances with a high solubility in water and loose binding to the fibres will be easily washed out. Direct dyes (used for light colours) are an example of substances that loosely bind to the fibre and are easily washed out whereas reactive dyes (generally used for darker colours) strongly bind to the fibres and will not easily be washed out (KEMI, 2014). However, excess reactive dyes may still be removed after the first washing. The Danish EPA summarized for a number of substances how well they are washed out (Danish EPA, 2011):

- Large washing out: Nonylphenol (NP) and nonylphenol ethoxylates (NPEOs), formaldehyde, various organic compounds, aromatic compounds and metals such as Ni, Pb, Zn, Ba, Cd;
- Medium washing out: arylamines derived from azo dyes;
- Limited/small washing out: antibacterial agents, metals and phthalates in PVC prints, metals such as Co, Cr, Cu and As, chlorinated carriers and polycyclic compounds.

Greenpeace investigated the effect of washing under simulated standard domestic laundering conditions for textile products in which NPEOs were identified (Greenpeace, 2012a). The results indicate that a single wash can wash out a substantial fraction of NPEO residues present within textile products. Washed fabric concentrations of NPEOs were between 6% and 83% of the concentrations in the unwashed portions of the plain fabrics (Greenpeace, 2012a).

With respect to antibacterial agents, it has also been shown that from biocide-treated textiles, considerable shares of silver, triclosan and triclocarban can be released after washing (KEMI, 2012).

It is not necessarily the case that the amounts of substances in textiles decrease after washing. ANSES quantified the skin sensitizing substance 1,4-paraphenylenediamine (PPD) in textiles which was regularly detected in black fabrics. Interestingly, PPD concentrations increased after washing (ANSES 2018). It was hypothesized that dyes containing PPD are unstable and that washing breaks down the dye and release PPD into the textile. Additionally, in a study by Wang et al. it was shown that bisphenol A (BPA), used as dye-fixing agent, could be transferred from clothing items with high BPA content to clothes with low BPA content (Wang et al., 2019). If clothes were washed without detergent, the amount of BPA in high content clothing items decreased whereas it increased in clothes with lower initial BPA levels. When detergent was used, this cross contamination was shown to decrease.

7.2.2 *Adding chemicals during use phase*

Consumers may also add chemicals to textile products during the use phase or contamination of textile products with chemicals occurs. For example, products may be treated with biocides. Older yarns and wool textiles, such as blankets and rugs, may have been treated with DDT or other pesticides that are not permitted today. Also outdoor clothing can be impregnated by consumers with for example permethrin, although home impregnation is currently not allowed in the EU. The same holds true for mattress covers which may be impregnated with permethrin to repel bed bugs (Faber et al., 2020). The use of insect repellents by consumers is not expected to occur on a large scale. Impregnation with products to increase the water repellence of textiles seems to be more common. A wide variety of products is for sale for this purpose, which are mostly marketed for outdoor clothing or jackets. Another type of products that are for sale to use on garments or home textiles are textile dyes or paint markers. An item of clothing can be dyed in the washing machine or painted on with special textile markers.

Textile might become contaminated with chemical substances during use, for example when something is spilled directly on clothing.

However, for consumer use, examples of contamination are currently not known to us. For professional clothing, contamination has been described for firefighting suits. Firefighter suits contain a high amount of polyaromatic hydrocarbon (PAH) substances that cannot be washed out by conventional cleaning (Duhoux et al., 2021). Hence, these PAH’s remain in the textile when mechanically recycled.

7.3 Substances of concern in textiles: measurements

There are a number of reports and studies available that provide an overview or measurements of potential hazardous substances in textiles. In general, risk assessments or actual exposure data in humans is lacking. Below we briefly summarise the reports relevant to the scope of this report. Additionally, all the findings of all studies where actual measurements of substances in textiles were performed, are summarised.

Finnish Environment Institute 2011
The Finnish Environment Institute wrote a report focusing on deficiencies in the risk management of chemicals in textiles and they also provided a list of hazardous substances that are used in textiles at the time (Assmuth et al., 2011). These include persistent organic pollutants such as Triclosan and PBDE, toxic chlorinated aliphatic industrial chemicals, phthalates, carcinogenic organic compounds such as azo dyes, sensitizing organic compounds, biocides and heavy metals and elements. The full table can be found in the article itself.

BfR 2012
Already in 2012, the BfR working group on textiles published a review and exposure assessment of the most relevant dangerous substances found in textiles and leather (BfR, 2012). The selected substances were: formaldehyde, glyoxal, flame retardants, antimony, 1,2,4-trichlorobenzene, organotin compounds, UV filters, perfluoric compounds, biocides, dyes, nano particles, (nano)silver, dioxins, residues of cleaning products and fabric conditioner. A table with the assessment of these substances is provided in the original report. Additionally, exposure for several dyes was calculated and a worst-case risk assessment was performed leading to a list of dyes that, according to BfR, should not be used in textiles.

KEMI 2013 + 2014
The Swedish Chemicals Agency (KEMI) has investigated in 2013 which hazardous chemicals are used in the textile production and provided a list of hazardous chemicals in the final textile product (KEMI, 2013). Textile analyses were conducted between 2005 to 2012. The substances found in finished textile articles were perfluorinated compounds, phthalates, heavy metals, flame retardants, isocyanates, organic tin compounds, antibacterial substances, free arylamines from disperse dyes and allergenic disperse dyes. Also, some organic compounds such as formaldehyde and various glycols were found in textiles. The report contains a non-exhaustive list of 165 chemicals that may be found in the final textile product. In 2014 KEMI identified approximately 3,500 substances as relevant for use in textiles based on several databases among which are REACH and the SIN list (KEMI, 2014). Of the 3,5000

substances about 2,000 were not yet registered under REACH. Of the 2,400 substances that were further investigated, 368 were considered to be a potential concern with respect to human health. The majority of these substances were direct dyes, acid azo dyes or fragrances, all functional chemicals which are added to the end product. Potential risks of auxiliary chemicals and impurities/degradation products were not taken into account as these are expected to be present in much lower concentrations in the finished article and therefore pose a lower risk. Of the 368 chemicals, 54 were in 2017 on the Dutch ZZS list (Wassenaar et al., 2017).

Prioritisation of chemicals (Nijkamp et al., 2014)
Similar to KEMI 2014, RIVM also prioritised hazardous substances for the use in textiles. The inclusion criteria used differed from the KEMI criteria, leading to somewhat different lists between the two reports. The hazardous substances in Nijkamp et al. were prioritised using a scoring system based on the type of use as registered under REACH, hazard classification and the potency of a substance (Nijkamp, 2014). Highest priority was given to 32 substances of which nine appeared to be Dutch ZZS substances in 2017, including dibutyltin-oxide, dicyclohexyl phthalate, diisobutyl phthalate, di(2-ethylhexyl) phthalate, cobalt dichloride, cobalt sulphate and hexabromocyclododecane (Wassenaar et al., 2017). Of the prioritised substances, information on exposure scenarios for consumers was often lacking or incomplete in the REACH registration database. Therefore, prioritisation based on exposure is not possible and realistic methods for the exposure and risk assessment of substances in textiles still needs to be developed (Nijkamp, 2014).

Danish EPA 2016
In 2016, the Danish EPA published a report in which the possibilities of recycling of consumer products were addressed and whether these are hindered by chemical substances contained in the products (Christensen et al., 2016). Outdoor clothing was one of the consumer investigated in this study. Examples of hazardous chemicals used in these products are phthalates occurring in PVC, which is used in rain jackets, as well as perfluorinated substances which are used as impregnation agents. The EPA considered a lack of knowledge on what happens to these substances during mechanical recycling. For example, the quantitative presence and the release of chemicals in or from unravelled material are unknown. Nevertheless, the Danish EPA was able to conclude in a qualitative manner, based on a downcycling scenario, that there may be a risk for consumers of inhalation of dust, as well as dermal exposure if unravelled material is used in for example mattresses or insulation material is possible.

ANSES 2018
From 2016 to 2018, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) identified chemicals that are responsible for causing skin allergies and irritation related to clothing or footwear (ANSES, 2018). New clothing and shoes were sampled that had been subject to consumer complaints. ANSES screened for 20 groups of chemical substances in clothing and 50 groups of substances

in shoes. The results of the screening for clothing are described in the Table below.

Table 4 Substances analysed in new articles: 25 clothing samples (ANSES, 2018).

Substance	**Total detection rate**	**Concentrations (in mg/kg textile)**	**Legal limit (current or future)**	**Use**
1,4-paraphenylenediamine (PPD)	Quantified in 20% of the clothing articles. Mostly in black fabrics. It is noted that PPD concentration increased after washing. It is assumed that dyes containing PPD are unstable and that PPD is released from the dye after washing.	13-56	To be regulated by REACH (restriction skin sensitisers: 250 mg/kg)	Dye
CI disperse yellow 23	Detected in one sample (out of 25) (purple drawstring).	31	To be regulated by REACH (restriction skin sensitisers: 130 mg/kg)	Dye
Heavy metals (cobalt, copper, antimony, lead, mercury, arsenic)	Quantified in 16% of the clothing samples. In a black button, plastic adjustment hook and strap fastener.	Cobalt: 10 -46.7 Copper: 2.5 – 56.9 Lead: 0.27 - 0.52 Arsenic: 36.5 - 84.2 Antimony: 0.41	Lead and arsenic are regulated by REACH (limited to 1 mg/kg of extractable lead, arsenic). Cobalt is to be regulated (restriction skin sensitisers: 70 mg/kg)	Plastics, paints/pigments, flame retardants (antimony)
Chromium	Quantified in 20% of the clothing samples. In a plastic adjustment hook, black lace, and black waistbands.	0.36 – 178	Regulated by REACH (limited to 1 mg/kg extractable Cr VI)	Dyeing additive
Nickel	Quantified in 16% of the clothing samples. In a plastic adjustment hook, another hook and a strap fastener.	0.1 – 87.7	To be regulated by REACH (restriction proposal skin sensitisers: 125 mg/kg)	Plating alloys

Substance	Total detection rate	Concentrations (in mg/kg textile)	Legal limit (current or future)	Use
Nonylphenols and nonylphenol ethoxylates	Quantified in 20% of the clothing samples. Mostly in black fabrics, in one grey and blue fabric and in two prints. It is noted that they were removed by washing.	Nonylphenol ethoxylates: 24 – 237	Regulated by REACH (limited to 100 mg/kg	Scouring agent for wool (degreasing). Washing and cleaning agents, spinning oils in textile manufacture. Dispersing and emulsifying agents in textile chemicals as well as impregnation agents in printing pastes.
Organotin substances (dibutyltin dichloride and monobutyltin trichloride)	Quantified in one clothing sample in a black coated fabric.	0.96 – 1.26	Regulated by REACH (limited to 0.1% by weight of tin)	Found in plastics/rubber, inks, paints, metallic glitter, polyurethane products and heat transfer material.
Formaldehyde	Was not detected in clothing. Was detected in several leather footwear samples.	Not applicable	Regulated by REACH (limited to 75 mg/kg)	Anti-creasing and anti-shrinking of textiles.
Polycyclic aromatic hydrocarbons (PAHs)	Were not detected in clothing.	Not applicable	Regulated by REACH (CMR restriction), thresholds for benzene (5mg/kg + 8 PAHs (1mg/kg each)	Contamination of carbon black, dyes or other petrochemical products. Can be present in rubber components.
Azo dyes or allergenic dyes	Were not detected in both footwear and clothing.	Not applicable	30 mg/kg (0,003 % by weight) or 0.1% by weight.	Used as dyes.
Dibutyl phthalate (DBP), diisobutyl phthalate (DIBP) and diethyl phthalate (DEP)	Were detected mainly in bra foams.	Not available	DBP and DIBP are regulated by REACH (limited to 0.1% by weight of the plasticized material)	Used in PVC prints on textiles. Adhesives, flexible plastic components.

Furthermore, ANSES analysed chemical substances in articles worn by 50 patients that were suspected of being associated with skin reactions. In shoes (made of leather), skin reactions were mostly attributed to 4-tert-butylphenol formaldehyde resin and chromium VI. For the clothing articles, the cases are currently still under evaluation. Nevertheless, based on the measured substances in both new and worn textile articles ANSES prioritized the following substances:

- 1,4-paraphenylenediamine
- 3,3'Dimethoxybenzidine
- 4-Aminoazobenzene
- Benzidine
- Nonylphenol
- Nonylphenol ethoxylates
- Disperse orange 37/76
- Anthracene
- Nickel
- Chromium
- Cadmium
- Dibutyltin

The study by ANSES served to support the restriction on skin sensitising and irritating substances on EU-level.

Overview of other studies where substances were quantified in textiles
Below in Table 5, a brief overview and literature list is given of all studies known up until now that have investigated the amounts of certain hazardous substances in textiles. The study by ANSES (2018) is not included as this was already summarized in more detail in Table 4.

Table 5 Overview of literature on measurements of hazardous substances in textile.

Reference	**Substance**	**Type of textile**	**Total detection rate**	**Concentrations and detection rates per concentration**	**Legal limit**	**Study setup**
(Greenpeace, 2012b)	Nonylphenol ethoxylates	Clothing	63%	Range: 1-45000 mg/kg >1000 mg/kg: 8,5% >100 mg/kg: 20%	0.01% by weight (100 mg/kg)	141 clothing items purchased worldwide analysed
	Phthalates (DEHP, DINP, BBP)	Clothing	100%	Levels up to 37.6% by weight in 4 samples. Low levels in remaining samples.	0.1% by weight (1000 mg/kg)	31 samples of plastisol printed fabric
	Azo amines	Clothing	1,5% (2 items)	1 item: 7 mg/kg 1 item: 9 mg/kg	30 mg/kg for regulated amines	134 clothing items purchased worldwide analysed
	Alkanes	Clothing	94%	NA	None	Qualitative screening on chemicals in 63 clothing items
	Benzyl benzoate	Clothing	19%	NA	None	
	Benzophenone 1,1'biphenyl BHT Benzyl napthyl ether	Clothing	NA	NA	None	
(Greenpeace, 2013)	Nonylphenol ethoxylates	Footwear and clothing	61%	1-10 mg/kg: 25% 10-100 mg/kg: 27% 100-1000 mg/kg: 6% >1000 mg/kg: 4%	0.01% by weight (100 mg/kg)	82 clothing items purchased and analysed.
	Aromatic amines	Footwear and clothing	None detected.		30 mg/kg for regulated amines	41 clothing items purchased and analysed.
	Phthalates (DEHP, DINP)	Clothing	94%	1 item: 11% DEHP by weight 1 item: 0.59% DINP by weight	0.1% by weight (1000 mg/kg)	35 samples of plastisol printed fabric

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
				31 items: <0.1% by weight		
	Organotins (monobutyltin and dibutyltin)	Footwear and clothing	27%	Range: 0.16 -0.48 mg/kg organotins in total	0.1% by weight of tin (1000 mg/kg)	21 articles with a plastisol print (results on footwear not shown here)
	Per- and polyfluorinated chemicals: - Ionic PFCs (PFOS, PFOA) - volatile PFC (FTOHs, FTAs)	Footwear and clothing	100%	Ionic PFCs (median; range): - Waterproof articles: 18.3 µg/kg; not detected to 2290 µg/kg - Swimwear: 3.51 ; 1.39 to 68 µg/kg Volatile PFCs(median; range): - Waterproof articles: 2383 18.3 µg/kg; Not detected to 6967 µg/kg - Swimwear: Not detected; not detected – 6967 µg/kg	1 µg/m^2 (PFOS) 25 ppb (C9-C14 PFCAs) 260 ppb (C9-C14 PFCA-related substances)	15 articles: waterproof articles, footwear and swimwear. (results on footwear not shown here) Note that recalculating the units here was not possible, so a comparison with legal limits cannot be made.
	Antimony	Footwear and clothing	36%	Median: 96 mg/kg Range: 14- 293 mg/kg	None	36 polyester or polyester blend articles
(Bruschweiler et al., 2014)	Aromatic amines which were at the time not regulated. The following were detected: - Sulfanilic acid	Colored clothing	17% released at least one aromatic amine	Total number of items per concentration range: <5 mg/kg: 10 samples	None	153 colored or black clothing items in Swiss and analysed for 22 aromatic amines of which 8

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
	- Aniline - p-Toluidine - 1,3-Phenylenediamine-- 4-sulfonic acid; 2,4-Diaminobenzenesulfonic acid - p- Phenylenediamine - 2,2′-Dimethylbenzidine - 4-Aminophenol: - 4-Ethoxyaniline			5-30 mg/kg: 21 samples > 30 mg/kg: 19 samples The most frequently found aromatic amines were sulfanilic acid (15 samples; 10%), aniline (9 samples; 6%) and p-phenylenediamine (8 samples; 5%)		were detected. The 22 amines were selected based on a toxicity prioritisation applied by the authors. Concentration ranges for all individual compounds are provided in the original paper.
	Aromatic amines which were regulated at the time.	Colored clothing	2/153 samples (1%) exceeded legal limits.	1 sample (red trousers): 362 mg/kg benzidine 1 sample (blue hat): 78 mg/kg 3,3′-dimethoxybenzidine	30 mg/kg for regulated amines	153 items of colored or black clothing in Swiss and analysed for regulated aromatic amines.
(Antal et al., 2016)	Approximately 40 different compounds are detected by a non-targeted screen.	Clothing		No concentrations measured. The most commonly detected hazardous substances were nonylphenol ethoxylates, phthalates, amines	Not applicable.	15 varying types of clothing items were analysed by direct analysis in real-time mass spectrometry (non-targeted screen). A full list of compounds detected per sample can be

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
				released by azo dyes, and quinoline derivates.		found in the original paper.
(Greenpeace, 2016)	Polyfluorinated chemicals (PFCs)	Outdoor products	90% (36/40)	In 11/40 of the products, PFOS exceeded 1µg/m^2 (PFOA legal limit is used as comparison by authors). In 6/40 products PFOA exceeded the legal limit up to 18.4 1µg/m^2.	25 ppb for the sum of C9-C14 PFCAs and their salts or 260 ppb for the sum of C9-C14 PFCA PFOA: 1µg/m^2	40 outdoor products (clothing, shoes, backpacks, tents) were sampled and analysed for polyfluorinated chemicals. Analyses of all individual articles and concentrations of all investigated PFCs can be found in the original report.
(Norwegian Environment Directorate, 2018)	Multiple substances among which di-(2-ethylhexyl) phthalate (DEHP), short chain chlorinated parrafins.	Sports items among which clothing	40%	In 20% of the products, legal limits were exceeded. No details on specific substances.	Multiple	Report is only available in Norwegian. In 44 sports products (among which were some clothing items), DEHP and SCCP were measured.
(Nederlandse Voedsel- en	Formaldehyde	Jeans	4%	Range: 8 – 31 mg/kg	75 mg/kg	104 jeans on the Dutch market were

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
Warenautoriteit, 2018)	Aromatic amines	Jeans	7%	Range: 0.2 – 4 mg/kg	30 mg/kg for regulated amines	tested for quantities of aromatic amines and formaldehyde.
(Wang et al., 2019)	Bisphenol A	New and used clothing	Used items: 100% New items: 98%	Median used items: 34.2 ng/g Median new items: 17.7 ng/g Range (all items): <3.30 – 1823 ng/g Bisphenol A can be transferred during laundry from clothes with high content to clothes with low content. Especially if no laundry detergent is used.	None	Study in China where 49 pieces of used clothing and 44 pieces of new clothes were analysed for bisphenol A and S. The fibre material was also taken into account as well as the effect of washing. Migration of BPA and dermal exposure was assessed.
	Bisphenol S	New and used clothing	Used items: 29% New items: 59%	Median used items: 5.67 ng/g Median new items: 12.3 ng/g Range (all items): <0.53 – 536 ng/g Geometric mean concentration of the sum of bisphenols was higher in non-cotton items.	None	

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
(Crettaz et al., 2020)	Aromatic amines both regulated and not regulated (22 compounds were detected in total).	Colored clothing	48% (non-regulated amines) 2% (regulated amines)	Total number of items per concentration range for non-regulated amines: 5-30 mg/kg: 12 samples >30 mg/kg: 60 samples - Polyester samples: 54% detection - Cellulose based fibres: 19% detection Total number of items for regulated amines: - 4- aminoazobenzene: 1 item (652 mg/kg). - 2,4-Diaminotoluene: 2 items (5-30 mg/kg)	30 mg/kg for regulated amines	150 colored or black clothing items were analysed for 58 regulated and non-regulated amines. Similar to Bruschweiler et al., 2014. Concentration ranges for all individual compounds are provided in the original paper. The item where 4-aminoazobenzene was found, was removed from the market.
(Carlsson et al., 2022)	Benzothiazoles (BT) and benzotriazoles	Clothing	BT: 22/24 items Benzotriazoles: 8/24 items (3 different compounds)	BT: Up to 230 ng/g Benzotriazoles: 8 ng/g up to 800 ng/g (varying per coumpound)	None	24 imported garments on the Swedish market were analysed by HPLC for a suspect and a non-target screening (oraganic compounds). Semi-
	Quinoline and methylquinolines	Clothing	Quinoline: 19/24 Methylquinolines: 12/24	Quinolines: up to 60,000 ng/g (highly varying per sample)	50 mg/kg (equals 50,000 ng/g)	

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
	Diisobutyl phthalate	Clothing	2/24 items	Highest concentration: 3300 ng/g	0.1 % by weight of the plasticised material	quantification was performed as well. Approximately 20 compounds were identified. Data on individual compounds can be found in the original paper.
	Nitroanilines (aromatic amines)	Clothing	Derivatives of dinitroaniline: up to 16/24 items Chloronitroaniline: 6/24	Derivatives of dinitroaniline: up to 5900 ng/g depending on the compound. Chloronitroaniline: 165,000 ng/g	30 mg/kg	
	Nitrophenols (NP)	Clothing	4-NP: 9/24 items 3-NP: 5/24 items 2,4-dinitrophenol: 3/24 items Chloronitrophenol: 3/24 items	Sum of NPs: 85 ng/g	None	
	Organophosphates	Clothing	Triphenyl phosphate: 5/24 items Tributyl phosphate: 1/24 samples	Highest concentrations were 44,000 ng/g for triphenyl phosphate and 530 ng/g for tributyl phosphate.	None	
	Arcidine	Clothing	5/24 items	Levels up to 940 ng/g	None	
(Danish EPA, 2021)	Nonylphenol	Knitting yarn (wool and cotton)	Not detected	Not applicable	None	45 yarn samples (wool or cotton) were tested for content of

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
	Nonylphenol ethoxylates	Knitting yarn (wool and cotton)	6/45 samples	One sample above the limit (purchased outside EU), the five other samples were between 4.8 and 62 mg/kg.	100 mg/kg	nonylphenol and nonylphenol ethoxylates as well as azo dyes and aromatic amines. Also migration analyses were performed for these substances and a series of heavy metals, formaldehyde, bisphenol A and permethrin. Eventually a risk assessment was performed. The results of these can be found in the original report.
	Aromatic amines	Knitting yarn (wool and cotton)	4/45 samples	Below limit values	30 mg/kg for regulated amines	
(Finnish Chemical Agency (TUKES), 2022)	Formaldehyde	Clothing and duvet covers	Not detected	Not applicable	75 mg/kg	Black jeans and colorful clothes and duvet covers from Finnish manufacturers and manufacturers outside the EU were tested. Numbers and
	Dimethyl fumarate	Clothing and duvet covers	Not detected	Not applicable	0,1 mg/kg	
	Nonylphenol ethoxylate	Clothing and duvet covers	Not detected	Not applicable	0.01% by weight (100 mg/kg)	

Reference	Substance	Type of textile	Total detection rate	Concentrations and detection rates per concentration	Legal limit	Study setup
	Quinoline	Clothing and duvet covers	Not detected	Not applicable	50 mg/kg	methods were not specified.
	Azo dyes	Clothing and duvet covers	Not detected	Not applicable	30 mg/kg for regulated amines	

7.4 Chemicals in post-consumer textiles

In the current system, information regarding substances and quantities present in textile materials is not generally passed on to potential recycling companies. For assessing the safety of recycling, a first step is to identify and quantify hazardous substances in recycled textiles. According to research from WUR there are no designed methods specifically for analysis of contamination in recycled textiles. However, methods to analyse contaminants in virgin textiles can be applied to recycled textiles as well (Peters et al., 2020).
The number of reports that discuss the potential presence of hazardous substances in textiles is limited. In this section, the results of research on this topic are summarized.

7.4.1 IKEA & H&M study

IKEA and H&M Group have joined forces in an effort to convert their work into circular businesses and have pledged to only use recycled, renewable, or other sustainably sourced materials by 2030. In an effort towards this commitment, a large-scale study has been conducted and more brands joined the study as contributors. The aim of the study has been to strategically increase knowledge, and overcome challenges to exchange data, and stimulate chemical transparency across the industry.
Post-consumer cotton, wool, and polyester textile waste sourced from different regions of the world were collected. The next step was to test these samples on the presence of chemicals using the RSL of AFIRM (Apparel and Footwear International RSL Management). The AFIRM RSL captures the most stringent regulation globally (including REACH) and in many cases includes additional chemicals or stricter limits to promote best practice and advance the industry. The following conclusions were drawn from the study (H&M group, IKEA and Chemsec (ngo)):

- Most substances included in the test plan were not detected in any samples of any fibre type, however some substances were detected above RSL limits.
- Although the overall detections were low, the distribution of the detections were widely spread among the tested samples.
- Fewer substances were detected in cotton compared to polyester and wool.
- For the post-consumer cotton, the test results indicated that alkylphenol ethoxylates (APEO) is the substance group with the highest probability to be detected, while azo dyes and other allergenic and carcinogenic dyes have an almost negligible probability of being detected.
- Polyester samples had the widest variety of substances detected.
- In wool almost all samples contained at least one substance that was detected above AFIRM RSL limits.
- APEO’s (alkylphenol ethoxylates) were detected in samples from all three tested fibres; cotton, wool and polyester. The most important APEO for the textile industry are NPEO (nonylphenol ethoxylates) and OPEO (octylphenol ethoxylates). In wool, NPEO was detected in every sample and was found above the RSL limit in almost all samples.
- The phthalates DBP (Dibutyl phthalate), DINP (Diisononyl phthalate) and DEHP (Di(2-Ethylhexyl)Phthalate) were

detected in polyester (DEHP above the RSL limit in 42 of the samples).
- For polyester, the perfluorinated chemicals (PFCs) and flame retardants were only detected in samples from UK.

The results are summarized in Table 6 and Table 7.

Table 6 Substances detected in post-consumer textiles above the RSL limit according to the AFIRM standard. Total amount of samples are 172 for cotton, 169 for polyester and 154 for wool (H&M & IKEA, 2021).

Substance name	**Amount of samples not compliant with AFIRM RSL**	**AFIRM RSL**	**Legal limit**	**Possible function of the chemical substance**
Nonylphenol ethoxylates (NPEO)	Polyester (9 samples) Wool (145 samples)	Total APs + APEOs: 100 ppm	0.01% by weight (100 mg/kg)	Detergents, scouring agents, spinning oils, wetting agents, softeners, emulsifying/dispersing agents for dyes and prints, impregnating agents, dyes and pigment preparations, polyester padding
1,2,4-Trichlorobenzene	Polyester (52 samples)	Total chlorinated benzenes/ toluenes: 1 ppm	None	Carriers in the dyeing process of polyester or wool/ polyester fibres or as solvents.
DEHP	Polyester (42 samples)	500 ppm	0,1 % by weight of the plasticised material	Flexible plastic components (e.g., PVC), print pastes, adhesives.
1,2,3-Trichlorobenzene	Polyester (41 samples)	Total chlorinated benzenes/ toluenes: 1 ppm	None	Same function as 1,2,4-trichlorobenzene
Extractable chromium	Cotton (3 samples) Polyester (29 samples) Wool (29 samples)	Babies: 1 ppm Adults and children: 2 ppm	1 mg/kg extractable CrVI	Dyeing additives; dyefixing agents; colorfastness aftertreatments; dyes for wool, silk, and polyamide (especially dark shades)
Cadmium	Polyester (29 samples)	Extractable: 0.1 ppm Total: 40 ppm	1 mg/kg extractable Cd	Pigments (especially in red, orange, yellow and green); stabilizer for PVC; in fertilizers, biocides, and paints.
Octylphenol ethoxylates (OPEO)	Wool (23 samples) Cotton (2 samples)	Total APs+ APEOs: 100 ppm	None	Same function as NPEO
1,4-Dichlorobenzene	Polyester (9 samples)	Total chlorinated benzenes/ toluenes: 1 ppm	None	Same use as 1,2,4-Trichlorobenzene
Azo amines and arylamine salts	Wool (7 samples)	20 ppm each	30 mg/kg for regulated amines	Azo dyes (dyeing)

Substance name	Amount of samples not compliant with AFIRM RSL	AFIRM RSL	Legal limit	Possible function of the chemical substance
Extractable nickel	Cotton (2 samples)	Extractable: 1 ppm	Restriction proposed 125 mg/kg	Nickel can occur as impurities in pigments and alloys.
BPA	Cotton (1 sample) Polyester (4 samples)	1 ppm	None	May be found in recycled polymeric and paper materials due to polycarbonate plastic and thermal receipt paper

Table 7 Frequently detected substances in post-consumer textiles with results above the detection limits (H&M & IKEA, 2021)

	Substance name	Detection rates (> detection limit)
Cotton	NPEO Barium DEHP MBT (organotin) Copper (extractable)	62% 37% 29% 27% 27%
Polyester	Pyrene (PAH) Nickel (Extractable) Fluorene (PAH) Acenaphtene (PAH) Fluoranthene (PAH)	45% 39% 35% 19% 14%
Wool	Formaldehyde Lead (total content) Barium (extractable) Copper (extractable) Cadmium (extractable)	51% 42% 38% 32% 20%

7.4.2 *User guide for end-users of recycled textiles by Research Institute of Sweden (RISE)*

In 2015, on behalf of the Swedish government, the report *Chemicals in textiles – Risks to human health and the environment*, was published by the Swedish Chemicals Agency. The report points out that substances used in production, for example in surface treatment, may remain in the final product, intentionally or unintentionally, and it is difficult to know exactly which substances remain and in what concentration. About 3500 substances have been identified as relevant for use in textiles. However, the actual use and level of presence in textiles had not been verified in that study.

For the publication by RISE, *User Guide- Classification and risk assessment of Textiles for Material recycling,* the background information from the aforementioned report was used to conduct analytical testing procedures for different types of materials and textile products. The chemical groups included in the analytical testing protocol were selected based on relevance (function in finished material, occurrence described in literature and experiential occurrence) in the specific materials. A wide range of post-consumer textile products was tested, including amongst others wind jackets, t-shirts, denim, work pants, swimwear. Some samples contained substances in a concentration that exceeded the OEKO-TEX limit value, however the concentrations were not exceeding the legal limit. One carcinogenic arylamine (3,3-dimethoxybenzidine) was found in the shirt fraction made of cotton. But the value was not above either OEKO-TEX or the legal limit value. The results are summarized in Table 8.

Table 8 Substances in post-consumer textiles above the OEKO-TEX standard (total amount of samples tested is 20) (RISE IVF et al., 2019).

Substance name	**Amount of samples which are not compliant with OEKO-TEX standard**	**Measured concentration in sample > OEKO-TEX standard**	**Function of the chemical substance**
PFOA	1 sample of wool	4,2 microgram/m^2	Water and dirt repellence.
chromium	1 sample of wool	1,0 mg/kg (extractable)	dyeing additives; dyefixing agents; colorfastness aftertreatments; dyes for wool, silk, and polyamide (especially dark shades
Chlorinated phenols	2 samples (swimwear from polyamide, wind/workout jackets from)	0,06 mg/kg 0,08 mg/kg	Chlorophenols are polychlorinated compounds used as preservatives or pesticides.
NPEO	2 samples of wool mixtures (Wool/Acrylic and Wool/other fibres).	151 mg/kg 173 m/kg (>100 mg/kg)	detergents, scouring agents, spinning oils, wetting agents, softeners, emulsifying/dispersing agents for dyes and prints, impregnating agents, dyes and pigment preparations.

7.5 Chemicals in recycled textiles

In this paragraph, the potential presence of chemical substances in post-consumer textiles is reviewed, and its potential to fulfil the legal thresholds will be assessed. As such, we assume that 100% recycled textiles are used for the production of new textile products, which represents a worst case scenario. It should be noted that the largest study on chemicals in post-consumer textiles did not mention the actual measured value, but reported only whether or not the AFIRM concentration threshold was exceeded. Therefore it is not always possible to evaluate whether legal thresholds have been met.

7.5.1 Some remarks with regard to potential risks for consumers

Application and exposure

Exposure of consumers to chemicals in recycled textile products is partly determined by the application of (recycled) textiles. Therefore, a good understanding of potential applications is required for determining risks for consumer safety. Exposure can occur via the dermal route (skin contact), via the oral route (uptake via mouthing (e.g. baby clothing)) or via the inhalation route (e.g. volatile substances).

In terms of volumes, most of the post-consumer textiles fibres that are collected and eventually recycled end up in other (downcycling)

applications (Frankenhuis, 2022; Royal Haskoning DHV, 2021b). In other words, the fibres are not used for new textile items (see chapter 3.4). Examples of such products are listed in the final row of Table 1. For some of these products, the most relevant route of exposure is no longer prolonged direct dermal contact such as insulation material, carpet underlay and parcel shelves. For the example of stuffed toys, no direct skin contact is assumed either.
For cleaning cloths, the exposure is the same as its original use, dermal contact. However, the duration of exposure can be variable depending on the (variety of) activities performed by workers using these cleaning cloths, and also whether or not the workers are wearing gloves. It was beyond the scope of this report to verify to which extent cleaning cloths made from recycled textiles are being sold in the Netherlands and to which extent workers can be exposed to chemicals from these products.

Regarding the use of post-consumer fibres for new textile products such as hand towels, t-shirts or jeans, the relevant route of exposure of the new use is comparable to the original use, which is dermal skin contact. As the use of recycled fibres for new textile products will have an impact on the quality of the final textile product, blending with virgin material is needed to achieve the desired quality and durability of the new products. As a consequence, in case the recycled fibre contains contaminants, the content will be reduced during blending (under the presumption that the virgin material is chemically compliant). Therefore, the potential concentration and exposure will be less compared to the use of 100% recycled fibre (mechanical recycling) which is technically not feasible at the moment.

Compliance versus risk
When a legal concentration limit is exceeded, it does not necessarily mean that there is a serious risk. Concentration limits are not always quantitatively based on a specific effect of the substance (health-based), but are frequently generally derived regulatory requirements. To determine actual health risks, a specific (risk) assessment needs to be performed.
To date, little information is available on potential risks of exposure to chemicals from recycled textiles for consumers due to the following reasons. Firstly, risk assessments on substances that migrate from textiles are very complex to perform and many assumptions need to be made as data on migration of substances from textile is scarce (Nijkamp et al., 2014). Secondly, only two studies have been performed in which hazardous substances were quantified in post-consumer textiles that may serve as input for recycling. Lastly, it is not yet quantified to what extent virgin textiles differ from recycled textiles with respect to hazardous substances.

7.5.2 Chemicals in post-consumer cotton
In the IKEA & H&M study, fewer substances have been detected in cotton compared to other textile fibres such as polyester and wool.
In 4% of the samples, a substance (OPEO, BPA, extractable nickel or extractable chromium) was present in a concentration higher than the RSL limit defined by the AFIRM standard. However, the AFIRM standard is in some cases stricter compared to existing chemical legislation, this is the case BPA and extractable nickel. For OPEO, the AFIRM standard is

also stricter as a threshold of 100 ppm is set which includes both alkylphenols (nonylphenol (NP), octylphenol (OP)) and alkylphenol ethoxylates (NPEOs and OPEOs), while the REACH restriction targets NPEOs only[12] (with the same threshold, 100 ppm). Also an exception is made for the NPEO restriction for recycled textiles.

As 2% of the samples exceeded the AFIRM RSL threshold for *extractable chromium (1 mg/kg)*, there is a chance that the REACH limit of 1 mg/kg extractable Chromium VI is not met. However, from the results it was not clear if the oxidation state of chromium was determined, and if a difference was made between chromium III and chromium VI. In the RISE study, extractable chromium was not detected (<0.3 mg/kg) in the cotton samples.

Extractable nickel exceeded the RSL threshold in the IKEA study in only 1% of the cotton samples. Nickel can be used in metal components in apparels and footwear such as rivet buttons, tighteners, rivets, zippers and metal marks. Some consumers may be more vulnerable to nickel allergy. The AFIRM threshold for extractable nickel is set at 1 mg/kg. In the RISE study, extractable nickel was not detected (<0.3 mg/kg) in any sample. Due to its allergenic properties, nickel is in the scope of the restriction proposal for skin sensitizers. The proposed threshold for nickel is 130 mg/kg w/w in textiles.

For *APEO's* the legal threshold has been lowered in 2021 from 1000 mg/kg to 100 mg/kg. Residual or trace concentrations of APEOs may still be found at levels exceeding 100 ppm, apparently more time is necessary for the supply chain to phase them out completely. However, for recycled textiles an exemption is made in the restriction.
The reason for the restriction is the fact that APEOs and its degradation products are environmental pollutants. European water bodies are at risk from the combined effects of NPEO degradation products, i.e. NP, short chain NPEOs and nonylphenol ethoxycarboxylates (NPECs), including effects arising from their endocrine disrupting (ED) properties.

Bisphenol A (BPA) was detected above the RSL limit in 1% of the cotton samples in the IKEA & H&M study, and was not quantified in the RISE study. According to Zhang et al. (2019) BPA can be transferred during laundry from clothes with high content to clothes with low content. Especially if no laundry detergent is used.
There is no direct restriction on the use of BPA in textiles. Only textile products being granted the EU Ecolabel are prohibited to contain BPA present in the article or in any homogenous part of it in concentrations of more than 0.1 % as BPA is included in the Substances of Very High Concern (SVHC) Candidate List under REACH. In its final Opinion, published in March 2021, the Scientific Committee on Consumer Safety (SCCS) concluded that a maximum of around 0.8 mg BPA/kg textile could be proposed to protect consumers. This limit value is different from the 130 mg/kg limit value that has recently been proposed for Category 1 skin sensitizers listed in Annex VI to Regulation (EC) No

[12] Nonylphenol is excluded from the scope of the restriction. Nonylphenol is not used in the textile manufacturing process. However, small amounts of Nonylphenol can be found in finished textile articles possibly due to the degradation of nonylphenol ethoxylates which are used in the textile manufacturing process or due to unintentional contamination of formulations used in textile processing.

1272/2008, like BPA, present in textiles (ECHA 2019). However, these values should not be directly compared to one another since the ECHA limit value intends to protect the consumer against local, sensitisation effects in the skin, while the limit value defined in the SCCS Opinion protects against systemic effects BPA may exert when present in clothing.

According to the IKEA & H&M study and RISE study, no *Polyfluorinated chemicals (PFC's)* have been detected in the cotton samples. This might be explained by the fact that textile products with water repellent properties are usually made from synthetic materials.

In 2018, NVWA investigated whether *azo dyes* and *formaldehyde* in jeans trousers in the Dutch market fulfill the requirements. All 104 jeans trousers investigated in the study, appeared to be compliant with the chemical safety requirements. In the RISE study one carcinogenic arylamine (3,3-dimethoxybenzidine) was found in the shirt fraction made of cotton. But its measured value was not exceeding either the OEKO-TEX or the regulated limit value.
Textile fibres from jeans are well suitable for mechanical (Frankenhuis, 2022). Azo dyes released from one of the 22 restricted aromatic amines are regulated since 2004. According to an expert with expertise in testing chemicals in textiles, aromatic amines are detected in only rare occasions (Centexbel, 2022). This corresponds with the results for azo amines gathered in Table 5 and 6.

For *formaldehyde* it can be expected that concentrations in recycled textiles do not exceed legal limit values because it will be (partially) washed out during use.

The phthalate *DEHP* was detected in 29% of the samples, however below RSL limit (500 mg/kg). The legal threshold (0.1% by weight) applies to the plasticized material in the article. Phthalates have been used in print (plastisol) pastes in the past, but are regulated by a REACH restriction since 2020. The reason why only traces of DEHP have been identified might be that the prints have been removed prior to testing, which seems to be a current practice during sorting processes (see chapter 3.4.3). However, it is hard to determine the exact sources of DEHP. In the studies compiled in Table 5, no information is available on content of DEHP in cotton, as only plasticized material was tested.

Conclusion:
Based on the available data, we can conclude that NPEOs may be found above current legal thresholds in post-consumer cotton. However, products made from recycled cotton are exempted from the NPEO restriction as the aim of the restriction was reducing environmental exposure. Extractable chromium was identified in a low amount of post-consumer cotton samples but no data are available to evaluate the potential presence of chromium VI specifically. There are no other substances identified above legal thresholds in post-consumer cotton. Based on the limited studies available, we can conclude that post-consumer cotton has a high potential to comply with current legal threshold values. Due to limited data available, it could be recommended to further and broader monitor some hazardous chemicals in recycled

textiles. We suggest to at least consider extractable chromium in future analytical testing programs of recycled cotton. Substances that have not been detected could be added to the testing program to verify the findings of the available studies. Depending on the origin of the textiles, the potential presence of brominated flame retardants and PFAS should be checked to assess potential chemical risks of using post-consumer cotton for new applications.
Also, it would be helpful to better understand the origin of extractable chromium in post-consumer cotton. Furthermore, good sorting practices, such as the removal of (PVC) prints are necessary to avoid contamination of cotton with phthalates.

7.5.3 Chemicals in post-consumer polyester

In the IKEA & H&M study, polyester had the widest variety of chemical substances detected. In 50% of the samples, one or more substances were present in concentrations higher compared to the RSL limit defined by the AFIRM standard. However the AFIRM standard applies in some cases stricter limits compared to existing chemical legislation.

Chlorobenzenes are responsible for the majority of detections above the RSL limit, but there is no legal threshold for these substances. Although no EU legal requirements exist to ban these substances in textiles, it has become a market-accepted requirement for textile brands. Leading apparel and footwear brands to ban the use of chlorobenzenes and chlorotoluenes in the production and manufacturing of their products. However, according to the IKEA study, the substances can still be encountered as contaminant.

In the same study, *extractable cadmium* was identified in 17% of the samples in a concentration above 0.1 mg/kg. The legal threshold is 1 mg/kg after extraction. Therefore, it is hard to say something about legal compliance for this substance. In the RISE study, extractable cadmium was <0.05 mg/kg in the 4 samples which contain polyester only or a blend with polyester.

Other remarkable results from the IKEA & H&M study:

- *DEHP* was detected > RSL limit in 25% of the samples and detected above 500 mg/kg (which is the AFIRM threshold). The legal threshold applies to the plasticized material in the article and is 0.1% by weight.
- *NPEO* was detected > RSL limit in 5% of the samples and BPA in 2% of the samples. As explained in chapter 7.5.2. there is an exception for the restriction of NPEO for recycled textiles and there is no restriction for BPA in textiles.
- *PFC's* had been detected in samples from UK only.

In the RISE study a substance from the chlorophenol group was identified in the polyester sample (wind and workout jackets), however its concentration is below the legal threshold value. PFC's have not been identified in these samples. It is not clear whether the sampled product group contains textiles with water repellent properties. Also non-fluorinated compounds can be used to achieve water repellence. A subset of PFAS substances have been analysed in both the IKEA & H&M study and the RISE study.

Conclusion:
Based on the limited studies available, it cannot be concluded whether polyester has the potential to comply with current legal threshold values. More research is necessary on the presence of DEHP and cadmium to evaluate legal compliance. Also PFAS could occur in polyester fabrics, however when the collected post-consumer textile products are not having properties like water or dirt repellency, it is expected that these products will meet the legal thresholds for these chemical groups. Due to limited data available, it would be recommended to monitor some hazardous chemicals in textile products from recycled material. It is suggested to at least consider extractable cadmium, DEHP for the verification of legal compliance in case recycled polyester is used as a resource for new products. It is also suggested to add quinoline as parameter, even though it was not found in polyester in the IKEA & H&M study. According to Table 5 it has been detected in studies on newly produced apparel. For the potential presence of chlorobenzenes and toluenes, more research is necessary in case polyester is increasingly recycled. For BPA, the SCCS opinion did not identify systemic health risks of BPA due to the use of clothing articles. The study is based on experimental migration rates of BPA from clothing into artificial sweat (Wang et al., 2019). The study recommends to investigate in future studies the reproducibility of the migration experiment and fabric specific migration rates. We recommend to consider the inclusion of recycled fabrics in case new migration studies are performed.

The recycling of post-consumer polyester fibres from textile products is being developed (CuRe, 2022) but not yet commercialized. For future analytical testing programs of post-consumer and recycled polyester we recommend considering to monitor:
- Extractable chromium and DEHP to verify legal compliance
- PFAS as the PFAS substances as these chemicals have been widely used for achieving water repellants properties in synthetic fibres and new restrictions are foreseen (see chapter 5.3.2).
- Quinoline
- Chlorobenzenes and toluenes
- BPA

7.5.4 *Chemicals in post-consumer wool*
In the IKEA & H&M study, almost all wool samples contained at least one substance in a concentration higher than the AFIRM RSL limits. NPEO was detected in every sample and exceeded the AFIRM RSL limit in almost all the cases.
Extractable chromium was detected above the AFIRM RSL limit in 19% of the samples. Remarkably, extractable chromium was mainly detected in samples from Northern Europe, and not in samples sourced from other regions. As said before, no distinction was made between chromium III and chromium VI in this study. In the RISE study, one wool sample contained 1,1 mg/kg extractable chromium VI, which exceeds the legal limit according to the REACH restriction for CMRs in textile articles.
Conclusion:
Based on the limited studies available, we can conclude that wool has difficulties to comply to current legal threshold values. More research is necessary on the presence of extractable chromium VI.

8 Conclusions and recommendations

8.1 Conclusions

8.1.1 Developments related to textile recycling in the Netherlands

The textiles market is highly globalized. Apparel is currently produced and consumed in a linear manner, which means that raw materials are extracted for clothing production and the products eventually end up in waste. In line with the circular economy ambitions set by the Dutch government for 2050, the realization of a circular economy in 2050, the recycling of textiles has become an important topic and specific policy measures (such as Extended Producer Responsibility) are taken to keep textile fibres in circulation for a longer period by reuse and recycling.
It is estimated that only less than 1% of material used to produce clothing is recycled into new clothing globally (Ellen Mc Arthur Foundation, 2018). According to policy monitoring, textile products in the Netherlands contain between 1 and 4% recycled content (Royal Haskoning DHV, 2021a, 2021b). However, there is currently no registration system for the use of recycled fibres in new clothes, and there is no information on the label available about the recycled content.

The most common method to increase the recycled content of textile products, is to use synthetic fibres from recycled plastics (e.g. spinning polyester fibres from plastic bottles), or by using cotton fibres from post-industrial sources (e.g. cutting waste).
Fibre-to-fibre recycling is currently an existing practice for cotton fibres via mechanical recycling. Collected post-consumer textiles are sorted by colour as well as material and fibres, and are shredded, including processes of defibrating. As the fibres are shortened during the recycling process, their functionality as well as quality deteriorate, making the addition of new and fibres necessary. Several brands produce garments with 15-20% content of mechanically recycled fibres (Roos S. et al., 2019). The maximum amount of recycled fibres in a jeans is about 40-50% according to manufacturers (personal communication Mud jeans, 2022).

The processes to recycle textiles into new clothes are still under development and taking place to a limited extent. The fibres recovered from mechanical recycling processes are often applied in a product with a lower functionality than the original material such as industrial cleaning cloth and non-woven (felt) applications used in the automotive (e.g. parcel shelves) and building sector (e.g. insulation). Chemical recycling is taking place to a very limited extent and has not reached commercial stage or market penetration on a large scale.

The EU Circular Economy Action Plan announced that for textiles, ecodesign measures shall be developed "to ensure that textile products are fit for circularity". Particularly, the planned revisions aim to set requirements for recyclability of textiles and to address the presence of hazardous substances and substances that limit recyclability. This initiative can stimulate the use of safer chemicals and chemicals that are compatible with established recycling technologies.

Challenges for the realisation of a safe and circular textile industry
A lack of demand for recycled textiles slows down investments and innovation in textile fibre recycling. In addition, recycled fibres have to compete with cheaper virgin fibres on the EU market. There are several factors that complicate the sorting and recycling of textile waste, making it expensive and rather unattractive for companies. The following bottlenecks are identified in this study, relating to the chemical content of recycled textiles:

- Post-consumer textiles are very heterogenous in their composition. Frequently fibre blends are used and plastic prints are often present that both hamper recyclability. Recyclability and disassembly are parameters that mostly not have been considered in the design of textiles products.
- The manual sorting of garments into different fractions for targeted recycling is a time consuming process.
- Information on the labels is not sufficiently specific for certain recycling processes. Especially information on the exact material composition is currently lacking. Labels in discarded textile items are often missing or washed-out.
- There is a lack of traceability of the materials and additives that have been used to produce textile.

8.1.2 Presence of hazardous chemicals in post-consumer textiles

Within the EU, several hazardous chemicals in textile products are restricted via regulations such as REACH and the POP regulation. Many countries have a national chemicals legislation similar to the EU legislation, for example Canada and the USA. On the other hand, the chemicals management regulation is less strict in many countries, especially in developing countries that dominate textiles manufacturing. Legislation per se is no guarantee for compliance. In addition, the EU chemicals legislation applies only to businesses and not to private citizens (Roos S. et al., 2019). This means that the growing share of privately imported goods from online stores outside the EU can pose a risk that textiles with hazardous chemicals eventually end up in post-consumer textiles. This risk is higher when buying from companies without physical stores in the EU and from marketplaces based outside the EU, as consumers may purchase products that do not comply with the requirements of the European chemicals legislation.

A garment produced with recycled fibres needs to be compliant with regulations of today. Ensuring compliance of recycled textile products can be challenging due the increasing number of restrictions and the increasing amounts of substances per restriction. It is practically impossible to visually judge or measure the average lifespan of collected clothing. The average lifespan of clothes was estimated at 4,1 years for the Netherlands, however it should be noted that clothing with a longer lifespan has more chance not be selected during the sorting process as “rewearable” (and resold elsewhere) and is thus more likely to end up as “recyclable”. Since 2020 new REACH restrictions relevant for textile articles have been put in force for (amongst others): CMR substances, NPEOs and phthalates. In addition, new regulation is being prepared for skin sensitizers in textiles and PFAS used as water repellent agent in clothing, such as outdoor clothing.

The same legal thresholds apply for new and recycled products. Only one exception was noticed for textiles in the long list of restrictions. It concerns the restriction for NPEOs (nonylphenol ethoxylate), a widely used chemical in textile industry, for which an exemption is made for recycled textiles. According to the restriction the uses of recycled textiles are not expected to contribute significantly to the release of nonylphenol (NP) and NPEOs to the environment, since the proportion is likely to be very small compared to the amount of articles made using new fibres.

Although certain chemicals are restricted for certain textile applications, they may be allowed for others because of the functionality that the chemical adds to the product. It is important to consider the differences from a legal point of view between applications. Therefore, it is important to know the chemical content of recycled textiles and whether it is allowed in the application foreseen for the recycled material.

A situation that should be avoided are when textiles that have been produced for no direct skin contact (such as curtains), enter a mechanical recycling process and are used in a textile application with direct skin contact. From the information available about collection and sorting, we can conclude that such practices are not taking place at the moment. As described in chapter 3, if mechanically recycled fibres are used, they originate mostly from jeans.
Risks can also occur when post-consumer textiles collected via citizens is mixed with other textiles such as professional clothing with water repellent properties or textiles from matrasses from hospitals or hotels with flame retardant properties. As these materials may contain hazardous substances, these waste streams should be handled separately. This is also a current practice and there are no hints of situations in which mixing of waste streams occurs.

Chemical in textiles during production and use
The production process includes different steps and different chemical (classes) are used in each step. The type of chemicals used are mostly depending on the fibre type, as such different chemicals can be used for cotton, polyester, wool, etc. When products are used, and washed by consumers, some substances can be washed out of the textile.
In general, substances with a high solubility in water and loose binding to the fibres will be easily washed out such as formaldehyde. For NPEOs, experimental results indicate that substantial fraction of NPEOs residues within textile products can be washed out after a single wash, however residual concentrations of NPEOs are still present in post-consumer textiles.
Also the opposite can occur, it was found that the concentration of substance 1,4-paraphenylenediamine (PPD) can increase by washing and bisphenol A (BPA) can migrate during washing and increase the content of BPA in clothing items (by migration from clothing with high BPA levels to clothing with low BPA levels).
We expect that there is a low risk of contamination with hazardous chemicals during use by consumers, except for outdoor clothing after treatment with waterproofing or biocidal sprays.

Chemicals in new and recycled textiles
There is only limited data available regarding the presence of hazardous substances in textiles. In this report, we have summarized the results of 12 studies. Only two studies have been identified in which post-consumer textiles have been analysed. The largest study was financed by a coalition of several brands, with IKEA and H&M in the lead for the organization of the study. Post-consumer cotton, wool, and polyester waste sourced from different regions of the world were collected. Fewer substances were detected in cotton compared to polyester and wool. Polyester samples had the widest variety of substances detected.

The other study on recycled textiles was performed by a Swedish Institute (RISE). The chemical groups were selected based on relevance (function in finished material, occurrence described in literature and experiential occurrence) in the specific materials. A wide range of post-consumer textile products was tested, including amongst others wind jackets, t-shirts, denim, work pants, and swimwear. Some samples contained substances in a concentration that exceeded the OEKO-TEX limit value, however the concentrations were not above the legal limit. Some notes for specific materials:

For all materials
Alkylphenol ethoxylates (APEO) is the substance group that was most frequently detected. According to REACH regulations, there is a restriction for NPEOs in textiles (nonylphenol ethoxylates) which is a subgroup of APEOs, and the threshold does not apply for recycled textiles. The restriction addresses the environmental risks associated with NP and NPEOs, and by restricting its use, emissions to surface water can be reduced.

Cotton
Three other substances (extractable chromium, extractable nickel and BPA) are identified in the post-consumer cotton that exceeded the RSL threshold in a very limited amount of samples. For BPA and extractable nickel, there is no legal threshold for textiles. For extractable chromium there is a restriction for chromium VI only. Based on the limited studies available we can conclude that the probability that post-consumer cotton complies with current legal thresholds is high. More research is necessary to clarify if extractable chromium VI can be present in post-consumer cotton. In the largest study performed by H&M and IKEA, 3 samples of 172 contained extractable chromium. We suggest to at least consider extractable chromium (VI) in future analytical testing programs of recycled cotton, and too test additional substances depending on the origin of post-consumer textiles.

Polyester
Chlorobenzenes were measured, there is no legal limit. DEHP and cadmium were detected above the RSL limit, but legal compliance cannot be verified as the actual measured concentration is not known. Based on the available studies it is not possible for polyester to evaluate the potential to comply current legal threshold values. More research is necessary on the presence of DEHP and cadmium. Also PFC’s can occur in polyester fabrics, however if the products have no properties as water or dirt repellency, it is expected that these products will meet the legal

threshold’s for these chemical (groups). We suggest to at least consider extractable cadmium, DEHP, chlorobenzenes and toluenes, and PFCs, quinoline and BPA in future analytical testing programs of recycled polyester.

Wool
In one study, the extractable chromium was detected above the AFIRM RSL limit (however, no distinction was made between chromium III and VI). In the other study, one sample contained chromium VI above the REACH limit. NPEO was detected in every sample however recycled textiles are exempt from the NPEO restriction. For wool, we can conclude that wool may have difficulties to comply to current legal threshold values. More research is necessary on the presence of extractable chromium VI in recycled wool to verify if it meets the legal thresholds, or not.

Also, it is important to note that in case a concentration limit is exceeded, it does not necessarily mean that there is a serious health risk. Concentration limits are not always quantitatively based on a specific effect of the substance (health-based), but are frequently general regulatory requirements. To determine actual health risks, a specific (risk) assessment needs to be performed.

As the use of recycled fibres for new textile products will have an impact on the quality of the final textile product, blending with virgin material is needed to achieve the desired quality and durability of the new products. As a consequence, in case the recycled fibre contains contaminants, the content will be reduced during blending (under the presumption that the virgin material is chemically compliant). Therefore, the potential exposure will be less compared to the use of 100% recycled fibre (mechanical recycling) which is technically not feasible at the moment.

8.2 Recommendations

8.2.1 Recommendations for market surveillance authorities such as NVWA

1) Analyse the impacts of an *increase of recycling for the Textile Fibres (nr. 1007/2011)* Regulation.
Recycled fibres are not clearly indicated on the product label. As such it is difficult to monitor the (increasing) share of recycled content for policy evaluations. Additionally, for companies selling recycled textile products, it may be difficult to conform to the Regulation on Textile Fibres (nr. 1007/2011). Reason for this, is that it is hard to determine the exact fibre composition of products that enter the recycling process, and therefore also to determine the exact fibre composition of a recycled fibre or product. The term ‘mixed fibres’ or the term ‘unspecified textile composition’ may be used on the label. As a consequence, the information to consumers is not clear. Enforcement authorities can check composition of fibres by analytical methods to verify compliance with Regulation 1007/2011. According to article 20 of the regulation 1007/2011, a manufacturing tolerance of 3% is permitted between the stated fibre and the percentages obtained from analysis. As such, textile products with recycled fibres can could exceed the manufacturing tolerance of 3%.

It is not known to what extent brands and companies using recycled content in their textile products have difficulties to be compliant with Regulation 1007/2011. As the fibre-to-fibre recycling rates are still low, but expected to grow in the future, we advise to survey to which extent this Regulation may hinder the realisation of circular goals for textiles, and to inform regulators if necessary as it could be considered to expand and/or adapt the current information requirements as laid down in the EU Textile Regulation (EU No 122 1007/2011).

2) Confirm safety of textile products with recycled content by performing additional testing
As noted, only 2 studies are available which have measured a set of hazardous substances in post-consumer textiles, so the input for recycled fibres. So, there is a need for information on hazardous chemical in clothing with recycled fibres on the market.

Based on the results on measurements in post-consumer textiles, it is currently not expected that wearing recycled textile products would cause health risks for consumers, for the following reasons:

- The use of post-consumer textiles is still in its infancy.
- From collected textiles, mainly cotton is recycled for new textile applications. In cotton, a lower variety of substances of concern has been identified compared to polyester and wool.
- Further, in the recycled textile, in most cases a mixture of virgin and recycled fibre is used.
- Some problematic substances will be partially washed out during use such as formaldehyde and NPEOs. Aromatic amines have been restricted since 2004 and are only found in rare cases.
- Prints are removed during mechanical recycling as such the risk of contamination with phthalates is reduced.
- PFAS are likely not present in cotton, as water repellent cloths are usually made from synthetic textiles.

However, since the data on chemicals in recycled textiles are scarce, NVWA could consider to verify findings and broaden the database by performing additional testing. Such a research could also be useful for communicational purposes as confirming the safety of recycled products is important for the societal acceptance of the circular economy.

3) Implement stronger enforcement measures to ensure safety of products from (online platforms) outside of the EU to ensure safe input for recycling processes.

When it comes to companies selling online, enforcing regulations, including REACH, becomes more difficult. The challenges of the global market and increasingly complex supply chains, as well as the increase in products sold online within the EU, poses specific challenges for Market Surveillance Authorities.

Stronger enforcement measures are needed to ensure consumers' safety and to ensure that textile items, once used, can be used safely for the production of new textiles. To this end, it is necessary to enable structured coordination and cooperation between national enforcement authorities and to streamline market surveillance practices. This is also acknowledged by the European Commission, as the EU strategy for sustainable and circular textiles published in March 2020, announced the coordination and support of cross-border market surveillance practices in the EU in priority areas to be proposed by the competent authorities. The Commission will provide support to step up collaborations between all relevant actors (customs and market surveillance authorities, industry and testing laboratories). With the release of the new Textile strategy there seems to be momentum to address this topic.

8.2.2 Recommendations for policy makers

1) Define criteria for sorting and recycling procedures
A discussion is needed between sorters and recyclers to discuss and eventually harmonize sorting procedures. Ideally, this discussion is taken place at a European level to guarantee that all Member States apply the same procedures and to guarantee a level playing field.

The sorting of textiles is nowadays done manually, and the primary goal is to sort out the items suitable for reuse. Sorting criteria to accomplish high quality feedstock streams for recycling are still in development. It is unclear to what extent the sorting criteria for recycling have been harmonised amongst the sorting centra nationally and outside the Netherlands. Stakeholders that have been interviewed for the purpose of this report mentioned the removal of prints (which can be made from PVC) to be a common practice, however it was beyond the scope of this report to verify if this a common standard applied throughout the recycling industry.

As the sorting is done manually, it is impossible to visually check the chemical content of collected textiles. There are initiatives to improve the detection of material composition at fibre level to raise the effectiveness of the sorting process.

As far as we know, there are no fast and readily available techniques to detect chemical content of textiles. However in some cases the potential presence of hazardous chemicals in collected textiles can be evaluated visually. As previously mentioned, this is the case for printed textiles (and potential presence of phthalates), and based on interviews with recyclers, it is already a common practice to remove printed textiles before it enters a mechanical recycling process. Another example are waterproof textiles used for winter jackets and tents which may contain PFAS. Even though not all PFAS substances are regulated yet, the restriction of the PFAS group is in preparation and therefore its presence will need to be addressed with increased recycling rates for textiles, and more specifically for synthetic fibres such as polyester.
To reduce the risks from chemicals such as phthalates and PFAS (for those chemicals for which it possible to link its use directly to a specific functionality), we recommend to align sorting procedures.

2) Increase knowledge on chemicals in (recycled) textiles
Policy makers can facilitate sharing of data and knowledge regarding chemicals in recycled textiles. An independent body is needed that organises cooperation between the government, businesses, and researchers. Such a knowledge platform could be connected to existing

initiatives such as the EPR or activities in the Circular economy transition agenda.

Only limited data are available regarding the presence of hazardous substances in recycled textiles (as well as in other textiles). Furthermore, as there are ambitious goals set for the use of recycled textiles (30% in 2030), we recommend to keep monitoring the presence of hazardous substances in post-consumer textiles to ensure this transition to a more circular textiles industry is safe for consumers. Due to these ambitious goals, more measurements will be necessary.

To gain a better understanding of the presence of chemical substances in post-consumer textiles also requires the improvement and harmonization of analytical methods, and more specific the development of non-targeted analyses for the identification of hazardous chemicals in textiles.

Chemical recycling techniques use chemicals and/or heat to recycle the materials. New chemicals can be formed in chemicals reactions induced by the presence of other chemicals and increased temperatures. The formation of non-intentionally added substances (NIAS) are a known concern in the recycling of food contact materials. More research is necessary to understand the risks for NIAS during chemical recycling of textiles and if these can be prevented by better sorting. On the other hand, some hazardous substances that were present in the source polyester may also be removed in the chemical recycling process.

3) Develop tools for industry to assess legal compliance for recycled textile products
Policy makers can facilitate collaboration between stakeholders such as the industry, surveillance authorities and researchers to develop tools for the assessment and verification of legal compliance of recycled textile products.

Due to the facts that textile waste is very heterogenous and that the number of regulated substances is large, it is practically impossible to test each batch according to the completes such as SVHC, ZZS or RSL. Product conformity with legal requirements (REACH conformity) needs to be assessed by chemical analyses. This is the responsibility of the entity that brings recycled products to the market. However this is costly.
By controlling and managing the different material flows (excluding textiles with prints) producers can limit the extent of external product controls and analyses, but they cannot exclude them completely.

Product safety of recycled textile products requires the development of an analytical protocol for measuring specific substances in recycled textiles.
For the plastics industry, a guidance document was developed how to deal with ZZS substances in waste streams. Also RISE, based on analytical research on recycled textiles, developed a protocol for measuring specific substances in specific textile waste streams intended for recycling. Both these examples could be a source of inspiration to

develop a similar guidance for monitoring the chemical quality of textile recycling.

4) Support 'design for recycling' and improve transparency on textile composition.

Policy makers can organize the development of an open-access platform to bring recyclers and designers together to improve design for recycling. In the context of the European Textiles Strategy and EPR regulation, a discussion will be needed between policy makers and industry how to manage data flows regarding the material type (specification of the fibres) chemicals in textiles and how to ensure that chemicals do not hamper recycling.

Recyclability is an important criterium to be able to realise a breakthrough of a circular textile economy, therefore design requirements (for easy disassembly) need to be developed and put into practice. Ideally, the (practical) bottlenecks experienced by recyclers are communicated directly to designers of clothing. Elastane for example, is a material that hinders recycling processes. Also information about chemical substances that hinders recycling processes, should be identified and via such a platform information could be shared amongst the companies and designers working on the development of safe & circular textile products.

With regard to the issue of transparency, it could be an option could be to digitalise data on the composition of textiles by introducing a digital product passport for textiles and machine readable data carriers. Such a solution would enable automatic sorting of textile wastes, increases the transparency, and possibly eases the monitoring and enforcement of REACH.
However, there are still a number of remaining challenges with regard to the implementation of a digital passport and the technology itself. A key challenge is how to deal with confidential data and how to manage the data flows in a practicable way, both for companies and for EU regulators and surveillance authorities. Overall, before a digital product passport for textiles can be implemented, extensive standardisation efforts and preparatory work are needed.

Hence, in order to further promote recycling-friendly textiles without hazardous substances, it is important to strengthen the research in safe alternative chemicals for textile production and promote the use of safer alternatives for problematic substances. It is important to encourage (EU) campaigns for the use of safe chemicals on the EU market and beyond. Also voluntary industry programmes (e.g., ZDHS and other RSLs) and certification schemes (e.g. OEKO-TEX) play an important role in the promotion of safe chemistry for textiles.

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10 Annexes

10.1 NEN definitions circular textiles

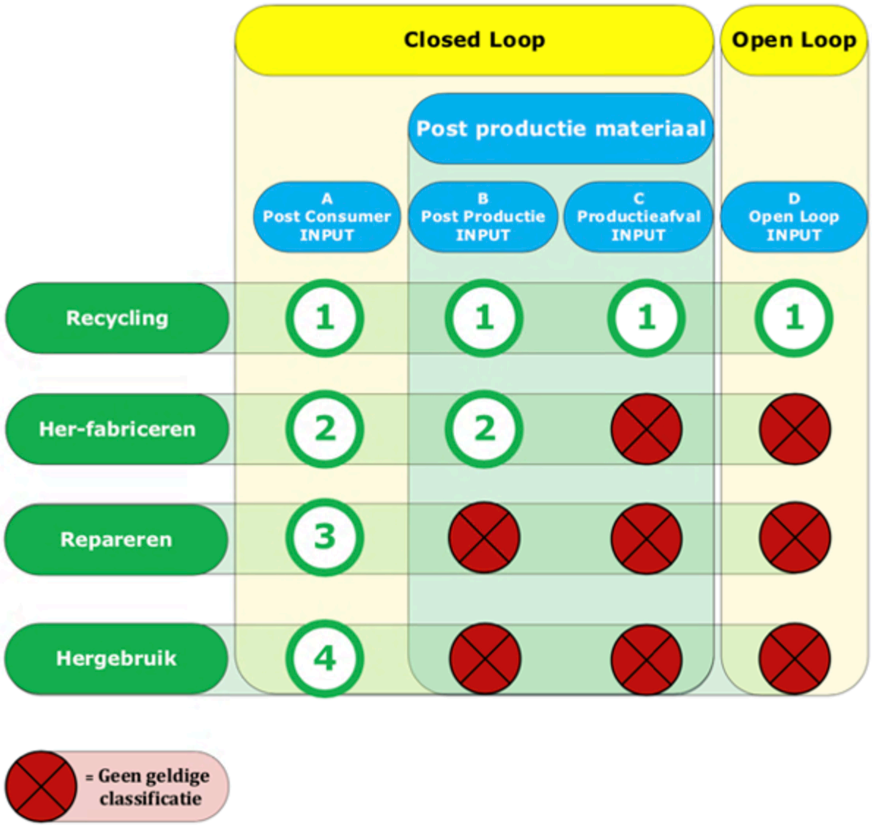

Figure 3 circular textile groups as described in the NTA 8195 "Circular textiles (Luiken, 2021)

In the current situation, there is no standardized standard to measure the circularity of a product or organization. Therefore, and to prevent 'greenwashing' in the field of circular textiles, the NEN has decided to develop a certification scheme for the textile sector. This so-called 'Dutch Technical Agreement 8195' describes circular textiles' and aims to be a standard for the Dutch circular textile industry. The following circular textiles groups are defined:

- A1 Product with recycled fibres from post-consumer textiles
- B1 Product with recycled fibres from post-production textiles
- C1 Product with recycled fibres from textiles production waste
- D1 Product with recycled fibres from non-textile products (open loop)
- A2 Product based on a remanufactured post-consumer textile product
- B2 Product on the basis of a remanufactured post-production textile product
- A3 Repaired post-consumer textile product
- A4 Reused post-consumer textile product

10.2 Appendix 12 to the REACH regulation (list of CMR substances, entry 72)

Substances	Index No	Cas No	EC No	Concentration limit by weight
Cadmium and its compounds (listed in Annex XVII, Entry 28, 29, 30, Appendices 1-6)	—	—	—	1 mg/kg after extraction (expressed as Cd metal that can be extracted from the material)
Chromium VI compounds (listed in Annex XVII, Entry 28, 29, 30, Appendices 1-6)	—	—	—	1 mg/kg after extraction (expressed as Cr VI that can be extracted from the material)
Arsenic compounds (listed in Annex XVII, Entry 28, 29, 30, Appendices 1-6)	—	—	—	1 mg/kg after extraction (expressed as As metal that can be extracted from the material)
Lead and its compounds (listed in Annex XVII, Entry 28, 29, 30, Appendices 1-6)	—	—	—	1 mg/kg after extraction (expressed as Pb metal that can be extracted from the material)
Benzene	601-020-00-8	71-43-2	200-753-7	5 mg/kg
Benz[a]anthracene	601-033-00-9	56-55-3	200-280-6	1 mg/kg
Benz[e]acephenanthrylene	601-034-00-4	205-99-2	205-911-9	1 mg/kg
benzo[a]pyrene; benzo[def]chrysene	601-032-00-3	50-32-8	200-028-5	1 mg/kg
Benzo[e]pyrene	601-049-00-6	192-97-2	205-892-7	1 mg/kg
Benzo[j]fluoranthene	601-035-00-X	205-82-3	205-910-3	1 mg/kg
Benzo[k]fluoranthene	601-036-00-5	207-08-9	205-916-6	1 mg/kg
Chrysene	601-048-00-0	218-01-9	205-923-4	1 mg/kg
Dibenz[a,h]anthracene	601-041-00-2	53-70-3	200-181-8	1 mg/kg
α, α,α,4-tetrachlorotoluene; p-chlorobenzotrichloride	602-093-00-9	5216-25-1	226-009-1	1 mg/kg

Substances	Index No	Cas No	EC No	Concentration limit by weight
α, α,α-trichlorotoluene; benzo-trichloride	602-038-00-9	98-07-7	202-634-5	1 mg/kg
α-chlorotoluene; benzyl chloride	602-037-00-3	100-44-7	202-853-6	1 mg/kg
Formaldehyde	605-001-00-5	50-00-0	200-001-8	75 mg/kg
1,2-benzenedicarboxylic acid; di- C 6-8-branched alkylesters, C 7- rich	607-483-00-2	71888-89-6	276-158-1	1 000 mg/kg (individually or in combination with other phthalates in this entry or in other entries of Annex XVII that are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in any of the hazard classes carcinogenicity, germ cell mutagenicity or reproductive toxicity, category 1A or 1B
Bis(2-methoxyethyl) phthalate	607-228-00-5	117-82-8	204-212-6	1 000 mg/kg (individually or in combination with other phthalates in this entry or in other entries of Annex XVII that are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in any of the hazard classes carcinogenicity, germ cell mutagenicity or reproductive toxicity, category 1A or 1B
Diisopentylphthalate	607-426-00-1	605-50-5	210-088-4	1 000 mg/kg (individually or in combination with other phthalates in this entry or in other entries of Annex XVII that are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in any of the hazard classes carcinogenicity, germ cell mutagenicity or reproductive toxicity, category 1A or 1B
Di-n-pentyl phthalate (DPP)	607-426-00-1	131-18-0	205-017-9	1 000 mg/kg (individually or in combination with other phthalates in this entry or in other entries of Annex XVII that are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in any of the hazard classes carcinogenicity, germ cell mutagenicity or reproductive toxicity, category 1A or 1B
Di-n-hexyl phthalate (DnHP)	607-702-00-1	84-75-3	201-559-5	1 000 mg/kg (individually or in combination with other phthalates in this entry or in other entries of Annex XVII that are classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in any of the hazard classes carcinogenicity, germ cell mutagenicity or reproductive toxicity, category 1A or 1B

Substances	Index No	Cas No	EC No	Concentration limit by weight
N-methyl-2-pyrrolidone; 1-methyl-2-pyrrolidone (NMP)	606-021-00-7	872-50-4	212-828-1	3 000 mg/kg
N,N-dimethylacetamide (DMAC)	616-011-00-4	127-19-5	204-826-4	3 000 mg/kg
N,N-dimethylformamide; dimethyl formamide (DMF)	616-001-00-X	68-12-2	200-679-5	3 000 mg/kg
1,4,5,8-tetraaminoanthraquinone; C.I. Disperse Blue 1	611-032-00-5	2475-45-8	219-603-7	50 mg/kg
Benzenamine,4,4′-(4-imino-cyclohexa-2,5-dienyliden-emethylene)dianiline hydro- chloride; C.I. Basic Red 9	611-031-00-X	569-61-9	209-321-2	50 mg/kg
[4-[4,4′-bis(dimethylamino)benz-hydrylidene]cyclohexa-2,5-dien- 1-ylidene]dimethylammonium chloride; C.I. Basic Violet 3 with ≥ 0,1 % of Michler's ketone (EC no. 202-027-5)	612-205-00-8	548-62-9	208-953-6	50 mg/kg
4-chloro-*o*-toluidinium chloride	612-196-00-0	3165-93-3	221-627-8	30 mg/kg
2-Naphthylammoniumacetate	612-071-00-0	553-00-4	209-030-0	30 mg/kg
4-methoxy-*m*-phenylene diam-monium sulphate; 2,4-diami-noanisole sulphate	612-200-00-0	39156-41-7	254-323-9	30 mg/kg
2,4,5-trimethylaniline hydro-chloride	612-197-00-6	21436-97-5	—	30 mg/kg
Quinoline	613-281-00-5	91-22-5	202-051-6	50 mg/kg

10.3 Proposed restriction on skin sensitisers, irritative and corrosive substances in textile and leather articles

Restriction on skin sensitizing substances in textiles
The restriction conditions proposed are as follows[13]:

Substances with harmonised classification as skin sensitisers in Category 1 or 1A or 1B in Annex VI to Regulation (EC) No 1272/2008 and the substances listed in Table 2 of the restriction:

1. Shall not be placed on the market for the general public in any of the following articles:
   i. Clothing and related accessories
   ii. Textile, leather, fur, hide and synthetic leather articles other than clothing which come into contact with human skin under normal or reasonably foreseeable conditions of use to an extent similar to clothing, such as:
      a. bed linen (e.g. sheets, duvet covers, pillow cases),
      b. blankets, throws,
      c. upholstery (coverings on chairs, armchairs and sofas, car seats, etc.)
      d. cushion covers
      e. bathrobes, towels,
      f. re-usable nappies and re-usable sanitary towels,
      g. napkins and table linen,
      h. childcare and children's products other than toys (valances, babies' nests, babies' deckchairs, bibs, baby car seats, etc.),
      i. sleeping bags,
      j. yarn and fabrics intended for use by the final consumer,
      k. bags like handbags, backpacks,
      l. carpets, mats and rugs,
      m. fashion accessories (e.g. wristwatch straps, necklaces, bracelets, etc.)
   iii. Disposable sanitary towels, napkins, tissues and nappies
   iv. Footwear

if they contain the substances in a concentration equal to or above the concentration specified in paragraphs 2 and 3.

2. The articles listed in paragraph 1 shall not contain substances (meaning exceeding the detection limit) belonging to the group of "disperse dyes", with harmonised classification as skin sensitisers in category 1, 1A or 1B in Annex VI to Regulation (EC) No 1272/2008, or listed in Table 2.
3. The articles listed in paragraph 1, shall not contain the following substances equal to or above concentrations specified below:
   I. Chromium VI compounds with harmonised classification as skin sensitisers in category 1, 1A or 1B listed in Annex VI to Regulation (EC) No 1272/2008 in individual concentration greater than 1 mg/kg w/w for materials specified in

[13] Restriction proposal can be accessed at: https://echa.europa.eu/nl/registry-of-restriction-intentions/-/dislist/details/0b0236e182446136

paragraph 1 (after extraction, expressed as Cr VI that can be extracted from the material except for leather, fur and hide where the concentration is 1 mg/kg (0,0001 % by weight) of the total dry weight of the leather, fur or hide)
   II. Formaldehyde in concentration greater than 30 mg/kg w/w for all materials specified in paragraph 1
   III. 1,4 paraphenylene diamine in concentration greater than 250 mg/kg w/w in textile and 80 mg/kg in leather, hides and furs
   IV. Nickel compounds with harmonised classification as skin sensitisers in category 1, 1A or 1B listed in Annex VI to Regulation (EC) No 1272/2008 in individual concentration greater than 120 mg/kg w/w in textile and 40 mg/kg in leather, hides and furs (after extraction, expressed as Ni metal that can be extracted from the material)
   V. Cobalt compounds with harmonised classification as skin sensitisers in category 1, 1A or 1B listed in Annex VI to Regulation (EC) No 1272/2008 in individual concentration greater than 70 mg/kg w/w in textile and 20 mg/kg w/w in leather, hides and furs (after extraction, expressed as Co metal that can be extracted from the material)
   VI. Substances not covered by paragraph 3 i-v and with harmonised classification as skin sensitisers in category 1, 1A or 1B listed in Annex VI to Regulation (EC) No 1272/2008, in individual concentration greater than 130 mg/kg in textile and 40 mg/kg in leather, hides and furs
4. Paragraphs 1 to 3 shall apply without prejudice to the application of any stricter restrictions or existing regulations.
5. Paragraphs 1 to 3 shall not apply to:
   I. Clothing, related accessories, textile, leather, fur, hide or synthetic leather articles other than clothing, or footwear within the scope of Regulation (EU) 2016/425 of the European Parliament and of the Council (*) or Regulation (EU) 2017/745 of the European Parliament and of the Council (**)
   II. Substances that are used as active ingredients in biocidal products within the scope of Regulation (EU) 528/2012.
   III. The placing on the market of second-hand clothing, related accessories, textile, leather, fur, hide and synthetic leather 3 articles other than clothing, or footwear which were in end-use in the Union before 31 January 2023.
6. When existing, the standards adopted by the European Committee for Standardisation (CEN) shall be used as the test methods for demonstrating the conformity of articles to paragraphs 1 to 3.

Table 2 to the restriction proposal on skin sensitisers containing a list of additional substances of concern (submitted by the dossier submitter):

Substance name	Cas No.	Ec No.
CI Disperse Blue 3	2475-46-9	219-604-2
CI Disperse Blue 7	3179-90-6	221-666-0
CI Disperse Blue 26	100357-99-1 13324-23-7 3860-63-7 2580-56-5	600-078-1 603-725-6 223-373-3 219-943-6
CI Disperse Blue 35	12222-75-2 56524-77-7	602-260-6 260-243-5
CI Disperse Blue 102	12222-97-8	602-282-6
CI Disperse Blue 106	12223-01-7	602-282-2
CI Disperse Blue 124	61951-51-7	612-788-9
CI Disperse Brown 1	23355-64-8	245-604-7
CI Disperse Orange 1	2581-69-3	219-954-6
CI Disperse Orange 3	730-40-5	211-984-8
CI Disperse Orange 37/59/76	13301-61-6 12223-33-5 51811-42-8	236-325-1 602-312-8
CI Disperse Red 1	2872-52-8	220-704-3
CI Disperse Red 11	2872-48-2	220-703-8
CI Disperse Red 17	3179-89-3	221-665-5
CI Disperse Yellow 1	119-15-3	204-300-4
CI Disperse Yellow 9	6373-73-5	228-919-4
CI Disperse Yellow 39	12236-29-2	602-641-7
CI Disperse Yellow 49	12239-15-5 54824-37-2	235-473-4 611-202-9
CI Disperse Orange 149	85136-74-9	400-340-3
CI Disperse Blue 291	CAS and EC numbers not specified, because there are numerous CAS and EC numbers associated with this chemical	
CI Disperse Violet 1	128-95-0	204-922-6
CI Disperse Violet 93	122463-28-9	602-785-0
CI Disperse Yellow 64	10319-14-9	233-701-7
CI Disperse Yellow 23	6250-23-3	228-370-0

10.4 Chemicals used in textile production processes

Table 9 Important chemicals or chemical classes used in different stages of textile and clothing manufacturing (Assmuth et al., 2011).

Fibre production	**chemicals or chemical classes**
Plant fibres (e.g. cotton)	pesticides, fertilisers
Wool and silk	pesticides, soda, detergents
Man-made fibres (e.g. viscose (rayon) or lyocell)	heavy metals, sulphides
Synthetic fibres (polyester, polyamide, polyacrylic and aramide)	heavy metals, acetaldehyde, 1,4-dioxane
Yarn production	**chemicals or chemical classes**
Spinning oils (Oils to reduce friction)	mineral or vegetable oil; emulsifiers; anti-mould agents
Fabric production	**chemicals or chemical classes**
Weaving- Sizing chemicals	starch based agents, alcohol, acrylate
Knitting- Lubricants	mineral oils (including PAHs), waxes
Washing	synthetic tensides; organic solvents, NPE/NPEOs
Desizing (remove starch sizes)	enzymes, alcohol, carboxy methyl cellulose, DDT, PCP
Scouring (remove grease, wax, base)	caustic liquor, acidic liquor
bleaching	hydrogen peroxide, chlorite, perborite, hydroxide
Mercerizing	NaOH
Dyeing, printing	azo dyes and other compounds
Attaching dyes to the fabric	acids, bases, salts (Fe, Cu, Al, Sn), carriers (also organic)
Auxiliary substances	solvents, formaldehyde, NPEO
Finishing	**chemicals or chemical classes**
Patterning	acid, base
Softeners	oil, paraffin, wax, alkane, fatty acids, silicones, PE, enzymes
Stiffeners	starch, PVA, resins, esters, starch, chlorides, CMC products
Stabilizing	formaldehyde, triazones, carbamates, N-alkylol compounds
Anti-shrink	acids, salts, N-alkanol compounds
Anti-pilling	enzymes
Water repulsion	salts, paraffins, Cl/F and Si compounds, pyridines, isocyanates
Oil repulsion	acids, polymers and other oil repellents
Dirt repulsion	oxides, clay minerals, PVC, phosphates, resins, F compounds
Fire-proofing	heavy metals, halogens, salts, formaldehyde, BFRs, SCCP
Antistatic treatment	polymers, synthetic tensides
Biocide treatment	phenols (also halogen), metals/Ag, NH4, SCCP, DMF

Finishing	**chemicals or chemical classes**
Moth proofing	acids, urea
Microencapsulation	fragrances, softeners, preservatives/biocides, potential drugs
Adding parts	metals including Cr and Ni in zippers, buttons etc
Coating	PVC, PU, pigments, inks, lacquers, Si, PFCs, waxes
Treatment of finished articles	soap, synthetic tenside, phosphates, zeolites, enzymes, silicates, brighteners, perfumes, metals, anti-mould, silicate, phosphonate, carboxymethyl cellulose, carboxylate glycol
Dry cleaning	tetrachloroethylene, trichloroethane, CFCs, hydrocarbons
Bleaching	perborate, percarbonate
Transport and storage	PCP, methyl bromide, chloropicrin, 1,2-dichloroethane

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