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Survey of chemicals in consumer products of recycled plastic

A risk assessment of textiles made of recycled plastic for children

Survey of chemicals in consumer
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Summary

The overall objective of the project is to build knowledge about the prevalence of consumer products containing recycled plastic, hereunder about the types (polymers) and origin of recycled plastic in consumer articles, which hazardous substances may occur in such articles, whether their occurrence is related to the recycling as well as whether these substances migrate from the plastic in an amount that may pose a risk to consumers, especially children, during the use phase. The study thus includes overall two parts; (1) a broad mapping of recycled plastic in consumer articles and (2) a narrow risk assessment focussing on specific group of consumer articles made of recycled plastic and on selected substances occurring in these.

The data collection for the mapping part of this study comprised a literature review, a survey of consumer articles made of recycled plastics at retailers' websites, and a stakeholder consultation including plastic recyclers, producers and compounders, article manufacturers and/or retailers, and manufacturer's and industry associations.

The data collection for the risk assessment relied mainly on publications from public agencies for the hazard identification. The exposure and risk assessment followed the respective ECHA guidances.

The key findings of this study are summarised for each topic under the objective of the study:

Plastic polymers in consumer articles made of recycled plastic. PET, including polyester, is the most abundantly used recycled polymer (41%) in the toys, childcare articles, textiles for clothing, home textiles, and furniture, which were the consumer articles in focus in the survey about recycled plastics. The traceability of PET was highlighted as being higher than for other polymers, being often collected separately, resulting in a more uniform and less contaminated plastic fraction. Other recycled polymers are PE, PP, PS, ABS, nylon and – to a lesser degree – PVC. For around 31% of the articles in the survey, that were advertised as made of recycled plastic, the polymer type was unknown.

Origin of the Recycled Plastics Used for Consumer Products. There is ambiguity and lack of information regarding the origin of recycled plastics in consumer articles. About half of the articles surveyed had an unspecified source of recycled plastic; approximately 40% were made from post-consumer recycled (PCR) plastics, and 10% from post-industrial recycled (PIR) plastics. The figures may be biased, as they are based on a relatively small number of consumer articles (62 articles) and on article descriptions from online retailers, who may have an interest in promoting their articles by claiming that they are made from PCR plastic.

Stakeholders emphasize that PIR plastic is easier to recycle due to its high purity and known composition. Estimates about volumes and distribution of PCR and PIR plastic could not be generated within the scope of this project. Overall, the data from the consumer article survey and the stakeholder consultation indicate that PCR plastic is more commonly used than PIR plastic in consumer articles with an expected increase of the volumes of PCR plastic.

Hazardous Substances in consumer articles made from recycled plastic. There are several reason why hazardous substances can be present in consumer products made from recycled plastic. One reason is the presence of additives that were originally in the virgin plastic products. These additives, added for functional purposes such as durability, flexibility, colour, or present as impurities, remain in the recycled material. Another reason is the

presence of legacy additives, which originate from the recycled plastic and were not intentionally added to the new recycled products. Additionally, the recycling process may involve the introduction of functional additives to enable the effective use of recycled plastic fractions such as heat stabilizers, odour maskers and/or pigments.

The literature review showed that numerous substances with hazardous properties can be present in consumer articles or recycled plastic material potentially used for consumer articles. Low levels of brominated flame retardants, organophosphate flame retardants, and some phthalates in consumer articles indicate that the substances' presence likely stems from the use of recycled materials or cross-contamination during recycling.

Many of the identified substances appear as legacy additives, which use in consumer articles is regulated and/or restricted via the REACH Regulation, POP Regulation, RoHS Directive and/or the Toys Directive, e.g., brominated flame retardants as PBDE, some phthalates, metals, eight PAH as well as some azodyes and the aromatic amine resulting from them. Other substances are only partly or not regulated in consumer articles via European regulations, e.g., novel flame retardants (such as TBBPA and its derivatives, brominated diphenyl ethyls and brominated phthalates), non-halogenated organophosphorus flame retardants, benzotriazole UV-stabilisers (except UV-328) and benzophenone-related UV-stabilisers.

Traceability and information transfer through the supply chain
The supply chain of recycled plastic articles on the Danish/European market involves numerous actors, who may be located both within and outside of Europe. The source and type of the recycled plastic is not always known in all parts of the supply chain.

The process from virgin plastic production to final consumer products includes steps where safety information, such as the Safety Data Sheet (SDS), may no longer apply or be accessible, particularly when the plastic is no longer in pellet form but has been transformed into an article. This complicates the recycling process when the used articles become post-consumer waste.

Knowledge about presence of chemicals in the plastic waste is generated during the recycling, re-compounding and manufacturing of recycled plastic articles steps. According to Waste Framework Directive (2008/98/EC), the analysis shall be performed by the actor who is obliged to ensure the end-of-waste criteria.

The methods and frequency of chemical analyses of the recycled batches are highly varying and depend on the recycled waste stream, the recycler's practice, and the customers' requirements. No standards exist for how often a batch of recycled plastic must be analysed for its content of hazardous chemicals, nor which chemicals should be investigated. Batch-specific declarations on, e.g., the content of metals, content of SVHC substances or CLP compliance, may be provided by recyclers or compounders on demand from manufacturers.

For the recycled plastic pellets, a safety data sheet is created and provided to the manufacturer of (recycled) plastic articles. The SDS informs the manufacturers that the plastic is made from recycled waste and must also include added hazardous additives and leftover hazardous substances from the first use if present above a certain concentration threshold.

Purchase of textile articles of recycled plastic and chemical analyses. In order to obtain data for the risk assessment, a specific article group was selected for further investigation via chemical analyses. The article group selected were textile articles of recycled polyester, which were marketed for children or where exposure of children was considered likely. 20 articles, comprising both home textiles, children's outdoor clothing and children's clothing with direct skin contact were purchased.

Firstly, the articles were screened by a non-target analysis for organic substances (GC-MS screening) and metals (ICP-MS screening).

The GC-MS screening identified a total of 194 substances of which about 60% could be identified with confidence. Based on the substance's concentrations, their number of detections, their hazard properties and regulatory status under REACH, eight substances and nine articles were prioritised for further investigation via migration analysis.
The presence of three – 12 metals could be identified per article in the ICP-MS screening. Overall, the concentrations of the metals found in the screening analysis did not cause any immediate concern with the exception of measured levels of antimony. However, the potential health risks related to the presence of antimony in recycled PET was not further investigated in the scope of this study.

Secondly, eight prioritised substances were included in migration analysis simulating exposure via sweat. Of these, only three substances were measured above the limit of detection in the sweat simulant at concentrations ≤ 100 mg/kg: 2,4-toluene diisocyanate (2,4-TDI), 2,6-toluene diisocyanate (2,6-TDI), and 4,4'-methylenediphenyl diisocyanate (MDI). These three substances belong to the chemical group of isocyanates that are usually associated with polyurethane (PUR), and not polyester, articles. However, isocyanates may also occur in virgin or recycled polyester due to their use in glues (used for fixation of different textile layers or decoration, their use in surface coatings of PET or their use as polymerisation additives in virgin or recycled PET. Their presence can therefore not be interpreted as being specific for textiles made of recycled polyester.

Risk assessment of substances identified in the textile articles made of recycled polyester.
Due to lack of applicable, quantitative hazard data for consumer use of diisocyanates-containing products, a quantitative risk assessment could not be performed. Thus, the risk assessment was conducted based on a qualitative approach for skin irritation, skin sensitizing, and/or carcinogenic substances.

For skin irritation, the health risks are considered controlled for both TDI and MDI, following the different applicable concentration limits for the CLP classification of mixtures.

Skin sensitizing and carcinogenic effects of the substances cannot be excluded, following the qualitative risk assessment methodology based on hazard bands as outlined in the ECHA Guidance. Additional considerations therefore need to be applied for the risk assessment.

The analytically determined levels of MDI in textile samples are well below the concentration limit of 0.1%, which is defined as the allowable content in the restriction entry for MDI under REACH. TDI levels are also well below the concentration limit of 0.1%, even though such a limit is not defined for TDI in consumer articles but for industrial or professional uses only. The hazard and risk assessments of TDI and MDI are of limited elaboration due to lack of hazard data, and the qualitative risk assessment cannot fully rule out whether the low levels of isocyanates that may be released from the textile articles made of recycled plastic can cause an unacceptable risk to children wearing such textiles. In any case, it is noted that there are no clear indications that diisocyanate substances are specific to recycled polyester, meaning that they could probably occur just as well in virgin textiles made of PET or PUR.

Abbreviations

Abbreviations will be spelled out in the text at first use.

Abbreviation	Meaning
ABS	Acrylonitrile-butadiene-styrene
ASA	Acrylonitrile-styrene-acrylate
B2B	Business to business
B2C	Business to consumer
BADGE	Bisphenol A diglyceride ether
BaP	Benzo[a]pyrene
BBP	Benzyl butyl phthalate
BDP	Phthalates
BFR	Brominated flame retardant
BHA	Tert-butyl-4-methoxyphenol
BHT	2,6-bis(1,1-dimethyl)-4-methylphenol
BPA	Bisphenol A
BPAF	Bisphenol AF
BPF	Bisphenol F
BPS	Bisphenol S
BTBPE	1,2-Bis(2,4,6-tribromphenoxy)ethane
BUV	Benzotriazole UV stabilizers
BBP (or BBzP)	Butyl benzyl phthalate
CMR	Carcinogenic, mutagenic or toxic to reproduction
DBDPE	Decabromodiphenyl ethane
decaBDE	Decabromo-diphenyl ether
DEEP	Diethyl ethyl phosphonate
DF	Detection frequency
DiBP	Diisobutyl phthalate
DMP	Dimethyl phthalate
DEP	Diethyl phthalate
DPP	Di-n-pentyl phthalate
DIDP	Di-‘isodecyl’ phthalate
DINP	Di-‘isononyl’ phthalate
DBP	Dibutyl phthalate
DEHP	Bis(2-ethylhexyl) phthalate
DCHP	Dicyclohexyl phthalate
DnOP (or DNOP)	Di-n-octyl phthalate
ELV	End of life vehicle
GC	Gas chromatography
HBB	Hexabromobenzene
HBCD	Hexabromocyclododecane
HDPE	High density polyethylene
HPLC	“High performance” or “high pressure” liquid chromatography
IR	Infrared
LC	Liquid chromatography
LDPE	Low density polyethylene
LDPET	Low density Polyethylene terephthalate
LMW	Low molecular weight

LOD	Limit of detection
LOQ	Limit of quantification
MS	Mass spectroscopy
nBFR	Novel brominated flame retardants
NBR	Acrylo-nitrile-butadiene rubber
OC	Operational conditions
OBIND	Octabromo-1,3,3-trimethylphenyl-1-indan
octaBDE	Octabromo-diphenyl ether
OPFR	Organophosphorus flame retardants or Organophosphate flame retardants
PAA	Primary aromatic amines
PAH	Polycyclic aromatic hydrocarbons
PAM	Polyacrylamide
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PBEB	2,3,4,5,6-pentabromoethylbenzene
PBT	Pentabromotoluene
PC	Polycarbonate
PCR	Post-consumer recycled
PE	Polyethylene
PES	Polyethersulfone
PET	Polyethylene terephthalate
PETG (or PET-G)	Polyethylene terephthalate glycol-modified
PIR	Post-industrially recycled
PLA	Polylactic acid
PMMA	Polymethyl methacrylate
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinylchloride
RDP	Resorcinol bis (diphenyl) phosphate
RHP	Recycled household plastics, sub-category of PCR plastic
RIP	Recycled industrial plastics
RMM	Risk management measures
RoHS Directive	Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment
RWP	Residual waste plastics
SAN	Styrene-acrylonitrile
SBC	Styrene butadiene block co-polymer
SBR	Styrene-butadiene rubber
SBS	Styrene Butadiene Styrene Block Copolymer
SDS	Safety data sheet
SEBS	Styrene-ethylene-buthylene-styrene rubber
SSWP	Source-segregated waste plastics
STOT RE	Specific target organ toxicity, repeated exposure
STOT SE	Specific target organ toxicity, single exposure
SVHC	Substance of very high concern
TBBPA	Tetrabromobisphenol A
TBOEP	Tris(2-butoxyethyl) phosphate
TCEP	Tris(2-chloroethyl) phosphate
TCP	Tricresyl phosphate
TCIPP	Tris(2-chloro-1-methylethyl) phosphate
TCPP	Tris(2-chloro-1-methylethyl) phosphate

TDBPP	Tris(2,3-dibromopropyl) phosphate
TDCP	Tris[2-chloro-1-(chloromethyl)ethyl] phosphate
TDCPP	Tris(1,3-dichloro-2-propyl) phosphate
TEHP	Tris(2,3-dibromopropyl) phosphate
TEP	Triethyl phosphate
TPhP/DPP	Triphenyl phosphate
UV	Ultraviolet
VP	Virgin plastics
vPvB	Very Persistent and very Bioaccumulative
WEEE	Waste electrical and electronic equipment
XRF	X-ray fluorescence

1. Introduction

1.1 Background

The circular agenda sets increasing requirements for companies to recycle plastic in the production of new products. Also, an increasing number of companies brand themselves as “eco”, “sustainable” or “green” by using recycled materials in the production of new articles, hereunder consumer goods. This trend requires a continuous focus on consumer safety, since potentially harmful substances stemming from the recycled plastic fractions may occur in new articles.

The Danish Environmental Protection Agency (in the following abbreviated as the Danish EPA) assesses, that there is a lack of knowledge about which plastic fractions are typically recycled in consumer articles, and which harmful substances may consequently be introduced into these consumer articles.

With this project, the Danish EPA wants to investigate, whether plastic fractions containing harmful substances are recycled in consumer goods and whether this recycling may pose a risk to consumers. The focus of the risk assessment is on children, as children are regarded as being particularly sensitive to the exposure to harmful substances.

1.2 Objective

The overall objective of the project is to build knowledge about the prevalence of consumer products containing recycled plastic. The project shall inform about:

- the types/polymers of (typically) recycled plastics in consumer products,
- the origin of the recycled plastics used for consumer products,
- which additives, degradation products and other hazardous substances (e.g., contaminants) that may occur in consumer products made of recycled plastic, and
- whether such substances have harmful health effects and may pose a risk to the consumer, hereunder especially children, during the use phase.

The project shall:

- provide the Danish EPA with knowledge about potential health risks for children related to the use of products made of recycled plastics,
- enable the Danish EPA to develop guidance for consumers about purchase of products made of recycled plastics, and
- enable suppliers or retailers to define criteria for recycled plastics within the supply chain.

Overall, the project is divided in two parts; the first part is a broad survey where general information of chemicals in consumer products made of recycled plastic are collected (Phase 1).

In the second part, a demarcated focus area is selected for further investigation, hereunder chemical analysis for certain compounds in specific consumer articles, and a human health risk assessment (Phase 2 and 3).

2. Survey of recycled plastics in consumer products

2.1 Objectives

The objective of Phase 1 is to map the existing knowledge concerning recycled plastics in consumer articles, with a focus on consumer articles that children may come into contact with. Articles in focus include toys of all kinds, childcare articles (e.g., child seats, car seats, strollers), children's clothing as well as furniture, home textiles and interior with which children can be expected to come into contact with during their everyday life.

The specific objectives of this phase are to:

- obtain an overview of which types of plastics are mainly used in consumer products.
- gain knowledge on the origin of the recycled plastics used for consumer products.
- mapping additives and degradation products that may occur in consumer products of recycled plastics, including their status under relevant EU legislation.
- describe the quality criteria applied by stakeholders throughout the value chain of recycled plastics as to ensure traceability and information about chemicals present in the recycled plastics.
- propose a focus area for investigation of chemicals in recycled plastics for phase 2.

2.2 Method

2.2.1 Literature search

Several approaches were used for identifying relevant literature for this project:

Firstly, grey literature was searched by using different combinations of the search terms "recycled", "chemical/hazardous substances/additives", "circular economy" and "plastics" in English and Danish in general web search engine (Google). Secondly, knowledge bases of organisations concerned with plastic recycling (Plastindustrien[1], Dakofa[2] and Plastic Change[3]) were reviewed. Using those two approaches 32 publications were found. Hereof 27 were found relevant as they either contained information on chemicals in consumer articles or on chemicals in recycled plastic in general.

Thirdly, a systematic literature search was conducted to find scientific publications on hazardous substances in recycled plastic. Relevant search terms were identified in a preliminary non-systematic search in which only titles of the search results were inspected.

The following search string was applied:

(("hazardous substance*" OR "hazardous chemical*" OR "harmful substance*" OR "harmful chemical" OR "substance of concern" OR SVHC OR SOC OR "chemical* of concern" OR "plastic additive*" OR "chemical additive*") **AND** ABSTRACT:(consumer* OR child* OR toddler* OR newborn OR infant* OR baby OR kids) **AND** (recyc* OR circular*) **AND** ABSTRACT:(plastic* OR toy* OR cloth* OR product* OR article* OR polymer* OR PET OR polyethylene OR "high density polyethylene" OR HDPE OR "low density polyethylene" LDPE

[1] https://plast.dk/plastindustriens-genavendelseskatalog/
[2] https://dakofa.dk/vidensbank/plast/
[3] https://plasticchange.dk/videnscenter/

OR “Acrylonitrile Butadiene Styrene” OR PE OR polyester OR polystyrene OR PS OR PVC OR "poly vinyl chloride" OR “polyvinyl chloride” OR polypropylene OR PP OR fabric* OR textile* OR furniture* OR carpet* OR foam OR mat)) **AND** (FIRST_PDATE:[2009 TO 2024])

The search yielded 134 hits in the Europe PMC database on 8 April 2024. Articles were screened based on title, abstract and full text, respectively. Articles were excluded if they did not contain specific information about harmful chemicals (i.e., concentrations or qualitative evidence of their presence) in recycled plastics. Articles about consumer products not marketed in the EU were also excluded. Furthermore, articles on microplastics and bioplastics were excluded.

Following a screening of abstracts, 117 papers were excluded as non-relevant based on the defined exclusion criteria. Following the full text screening, the remaining 17 articles were excluded, yielding no relevant papers. Many of the articles contained information on additives in virgin plastics and mention implications for recycling, however, do not provide specific information on additives in recycled plastic. During the full text screening, five additional publications were identified through the references of the articles.

2.2.2 Survey of consumer articles made of recycled plastics at retailers

For identifying articles on the Danish and EU market, an open search using different words for recycled plastic products was done using general searches on Google and Amazon. Also, stakeholders were asked, and their websites were reviewed to identify articles made of or containing recycled plastics. The search targeted both articles intended for children, as well as articles with which children can be expected to come into contact with during everyday life according to the agreed scope within this project.

Different combinations of the following search term were applied in the open searches:

- Danish: genanvendt, recycle*, plast, børn, børnemøbler, møbler, bestik, pusle*, pude, tæppe, tøj, legetøj, småbørnsartik*
- English: recycle*, plastic, children, furniture, cutlery, pad, cushion, blanket, cloth*, toys, childcare

Articles were listed in an excel sheet with information including article category, type of plastic, origin of plastic, state of plastic (flexible/rigid), colour, country of manufacturer and retailer, and price. Additionally, based on the article description on the article’s website and the project team’s estimation, the exposure duration, most relevant exposure routes, and the age range of the expected target group was noted. In the selection of articles to list in the excel sheet, focus was on covering as many different manufacturers/brands and product types as possible. That means, e.g., if a retailer offers several articles, which are from the same manufacturer and/or of the same type, but available in different shapes/color, only information about one of the articles from this retailer was noted down.

2.2.3 Stakeholder consultation

Stakeholders from the plastic recycling and producing industry as well as retailers and manufacturer’s associations were contacted during April and May 2024. The number of stakeholders from the respective parts of the supply chain and responses received are presented in TABLE 2-1. Several stakeholders preferred to not disclose their name; hence, answers are anonymised in section 2.3.1. The questionnaires used in the stakeholder consultation can be seen in Annex 1.

TABLE 2-1. Number of stakeholders contacted, and responses received.

Category of stakeholders	Number of stakeholders contacted	Number of responses received
Recyclers, producers and/or compounders	10	4
Article manufacturers and/or retailers	12	5
Manufacturer's or industry associations	12	3
Total	**34**	**12**

2.3 Results of the survey of recycled plastic in consumer products

In the following sections, the results from the data collection (literature survey and stakeholder consultation) and the survey of consumer articles made of recycled plastic are reported.
This subchapter (2.3) is divided in three main sections:

- Section "2.3.1 Supply chain and life cycle of recycled plastic for consumer articles" gives an overview of the supply chain and life-cycle of recycled plastic in order to identify the steps in which (amongst others) additives are added and how information on this is transferred through the supply chain
- Section "2.3.2 Consumer articles made of recycled plastics" reports the findings of the survey of consumer articles made of recycled plastics at retailers, including information on the plastic types (polymers) used and the origin of the recycled plastic
- Section "2.3.3 Hazardous substances in consumer articles made of recycled plastics"

2.3.1 Supply chain and life cycle of recycled plastic for consumer articles

This section summarises the life cycle of plastics including their recycling as well as their typical supply chain. Information on where additives may be added through the life cycle as well as which information is passed on through the supply chain is provided. Available information regarding traceability of recycled plastic, quality documentation and requirements is reported under the respective life cycle steps.

An overview of the life cycle of plastics including their recycling can be found in FIGURE 1.

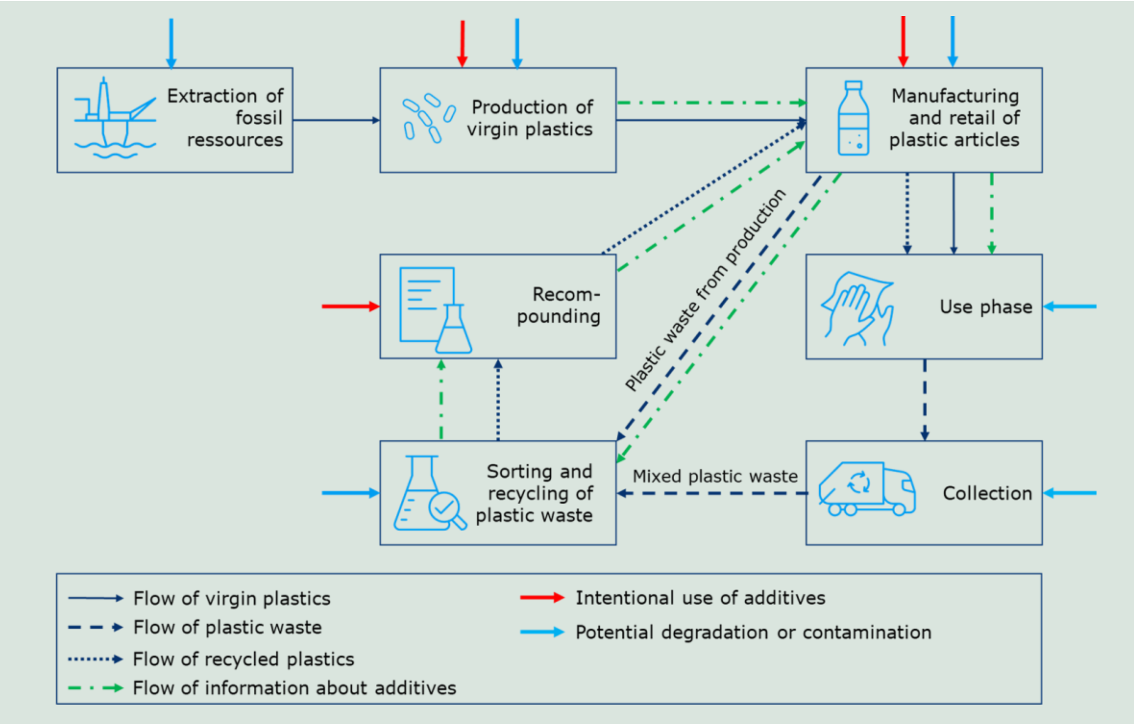

FIGURE 1. Life cycle of virgin and recycled plastic products. Inspired from Eriksen et al. (2018).

As outlined in FIGURE 1, all life cycle steps except extraction of fossil fuels are of interest in this project, as hazardous substances may occur in all steps. During production of virgin plastic, manufacturing of (recycled) plastic articles and during re-compounding of recycled plastic, additives are added intentionally. Degradation of substances in the plastic material or contamination of the plastic may occur during the use phase, or during the collection, sorting and recycling of plastic waste.

In order to achieve an understanding of the involved actors and their purpose within each step in the supply chain, the following terms are defined for the description of the life cycle steps in this chapter. However, it is important to note that these terms are not standardised, and different wording may appear in different literature.

- Producer – A producer produces virgin plastic raw material to be sold to a manufacturer of plastic articles. Depending on the need of the manufacturer, the producer may add additives to the plastics.
- Manufacturer – A manufacturer produces new articles based on virgin or recycled plastics. Manufacturers can add additives to their articles, depending on the needs of the application and/or end-user. Manufacturers may sell their product directly to the customer or via a retailer.
- End-user – The end-user is the person (or company) which uses the article produced by the manufacturer. After the use, the end-user can either re-sell the article or discard it.
- Collector – A collector collects (plastic) waste from the end-user or from specific drop-off points. In some cases, the collector also sorts waste (sorting facility) and recycles waste (recycler), depending on the capabilities and size of the company.
- Sorting facility – A sorting facility sorts the incoming waste into specific fractions. During this step foreign material (e.g., wood, glass, paper) and high value materials (e.g., batteries, printed circuit boards) in the waste stream are removed. Often there will also be a sorting of plastic types. The pre-sorted waste is then sent to a recycler. In some cases, a sorting facility also recycles waste.

- Recycler – A recycler further cleans and sorts the incoming waste to produce outputs containing only one type of polymer. The waste originates either from a manufacturer, a collector, or from a sorting facility.
- Compounder – A compounder melts the recycled plastic fractions into pellets (or similar) and then sells them on the market to a manufacturer. In some cases, a recycler also compounds their own output. The compounder may add additives to their plastics, depending on the need of the customer.

The different parts of the supply chain may be represented by companies specialised in one or more of the steps. For example, some companies are both collectors, recyclers, and compounders (e.g., Plastix)[4], while others are both article manufacturers and retailers (e.g., Dantoy)[5].

Furthermore, the term 'recycled plastic fraction' is used for a of waste fraction of plastic, that is recycled, and may consist of one or several plastic polymers as well as potentially contain harmful substances. In contrast, the term 'polymer' is used for a specific type of plastic polymer (e.g., polyethylene, PE, or polypropylene, PP).

During the stakeholder consultation, companies from all parts of the supply chain (except end-users) have been interviewed: manufacturers, collectors, recyclers, compounders, and retailers as well as several industry associations. The information provided in the following subsections is aggregated from the results of the stakeholder consultation, the project team's professional experience and supplemented by recent literature on the topic.

2.3.1.1 Production of virgin plastics

Virgin plastics are produced from fossil fuels. Bio-based plastics are also available on the market; however, these are excluded from the scope of the current project.

For production of virgin plastics, a chemical producer either purchases the monomers for the polymer in question or produces the monomers themselves, depending on their size and capabilities. This way typical polymers such as PE, PP, polystyrene (PS), polyethylene terephthalate (PET), and acrylonitrile-butadiene-styrene (ABS) are produced. Some producers also produce specialised polymers for niche applications. Most plastics in Europe are used for packaging followed by building and construction applications, automotive industry, and electronics (PlasticsEurope, 2023).

The producer may add certain additives in order to obtain the required properties. This may include plasticisers, colourants, flame retardants, stabilisers etc. The plastics are usually sold as pellets which can be molten and shaped into the desired form (Andersson et al., 2019).

The downstream user, typically another company, buys such pellets and may be entitled to a safety data sheet (SDS) according to Article 31 of REACH (1907/2006). However, not all substances (i.e., additives) need to be mentioned in the SDS. For example, if a substance is not classified under CLP or if the concentration of a classified substance is below a certain threshold, it does not need to be included in the SDS. In some cases, confidential business information may also be omitted from the SDS. If no hazardous substances are present in the mixture, or the substances themselves are not hazardous, then no SDS is required according to the provisions in Article 31 of REACH. Thus, only information about hazardous substances is communicated to the customer.

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[4] https://plastixglobal.com/howwedoit/

[5] https://www.dantoy.dk/en

2.3.1.2 Manufacturing of articles of virgin plastic

The downstream users melt the pellets, add additives if necessary and form the melt into the desired shape. For some purposes, e.g., in many packaging applications, additives are not required, as packaging plastics typically do not need special properties such as, e.g., flame retardancy. The manufacturer sells their product either directly or via a retailer to the end-user (e.g., toys) or to another manufacturing company (e.g., a plastic seat to a manufacturer of chairs).

The manufacturer again has the obligation to provide a SDS to the recipient, if their product is a substance or a mixture (Article 31 of REACH). This means that a SDS shall be provided throughout the supply chain as long as the product is a substance or a mixture and contains classified hazardous substances above the defined concentration thresholds. Article 34 of REACH also requires any supply chain actor to pass on new information about hazardous properties to the next actor or distributor up the supply chain, if new information on hazardous properties becomes available.

If the plastic has been formed into a specific shape, surface, or design, which is defining for the use of the product, it is classified as an article (for example a plastic seat; see also the definition of “article” in Article 3 of REACH) and not a substance or a mixture. As such, the SDS and other obligations for substances and mixtures are no longer applicable. However, for articles, the supplier has the obligation to communicate the presence of substances of very high concern (SVHC) above 0.1 % by weight to the recipient of that article (Article 33(1) of REACH). On request, the supplier also has the obligation to communicate the presence of substances of very high concern (SVHC) above 0.1 % by weight to the consumer (Article 33(2) of REACH).

During the manufacturing phase, a fraction of the plastic is usually generated as waste. This fraction either contains no or a known quantity of additives, consists of only one polymer, and has not been used further. Hence, the post-industrial plastic waste fraction is of high quality. This fraction may be sold to recyclers and re-compounded into recycled plastic pellets. For such fractions, an SDS may be provided to the recycler (according to communication with recyclers). The resulting material is referred to as post-industrially recycled (PIR) plastics.

2.3.1.3 Use phase

During the use phase, additives are typically not added. However, users may add substances to the surface of an article e.g., paints, coatings, or impregnation sprays for water repellency, by storing unintended chemicals in the product or chemicals from cleaning the product.. Such materials/substances will then also be present in the waste stage.

Furthermore, new potentially hazardous substances can possibly occur in the plastic products due to degradation of additives or contaminants added earlier in the product’s life cycle (Dahl et al., 2024) or due to degradation/depolymerisation of the plastic polymer itself. For example, for products used outdoors or in conditions with elevated temperature, degradation of the polymer or additives may take place, creating potentially hazardous substances and lowering the quality of the plastic (often indicated by a yellow colour) (Zaini et al., 2024). In food contact materials, monomers, yielded from the degradation of the plastic polymers, may migrate from the plastic material and into the food (Hahladakis et al., 2018).

Ultimately, the product becomes unusable and is disposed of as waste. The end-user does usually not know which hazardous substances are present in the products. As such, when post-consumer waste arrives at the recycler it is typically not known which hazardous substances are present, as this information is lost during the use phase.

2.3.1.4 Collection

Collection of plastic waste can take place directly from industrial production plants as production waste (PIR plastic), from households, from recycling sites and as commercial plastic waste (excl. production waste) (PCR plastic).

The collection of (plastic) waste is organised differently between geographic regions (countries, municipalities etc.). Often it is split between pickup services for (mixed) household waste (collectors), recycling points (for e.g., WEEE and bulky waste), bring-to sites, and deposit return systems (e.g., beverage bottles) (ICIS, 2023). Generally, most household plastic fractions are a mixture of multiple types of plastic polymers which may need to be separated in order to enable high quality recycling.

The collection of waste plays an important part in separating products potentially containing hazardous substances from those that do not. For example, plastics from end-of-life vehicles (ELV) or from waste electrical and electronic equipment (WEEE) often contain hazardous substances such as flame retardants, stabilisers, and UV-filters (Haarman et al., 2020), many of which are already restricted and thus need to be removed. For this reason, the WEEE Directive (2012/19/EU) establishes categories of EEE to be collected separately. This ensures a higher homogeneity in the waste streams which facilitates more efficient recycling.

The recycling potential of a waste stream may be influenced by the degree to which different plastic polymers are separated during the collection. For example, PET bottles are often collected separately via a deposit return system creating a homogeneous PET waste stream (ICIS, 2023). As little to no other polymers (or other impurities) are present in this waste stream, the PET can be recycled with high quality. This makes recycled PET suitable for future applications for which certain requirements must be met such as for food contact materials or cosmetics and cleaning products packaging, the latter having less well-defined requirements to purity and traceability (Dahl et al., 2024). However, as reported by Hahladakis et al. (2018), the sorting and reprocessing steps are even more important than the collection step for the final quality of the recycled plastic.

2.3.1.5 Sorting and recycling of plastic waste

The aim of the sorting and recycling process is to create separate plastic fractions for each polymer type, or at least plastic fractions in which the polymer composition and purity is known. Knowledge of the input material in a manufacturing process can be essential to enable documentation of the final recycled plastic product, including possibly the effectiveness of decontamination, in accordance with relevant legislation

Ideally, the sorted plastic fractions should contain only one polymer type with no impurities (i.e., other polymers or materials such as wood, glass, paper etc.) and be free of hazardous substances. The latter is also required by EU law such as the REACH and POP Regulations, both of which restrict certain substances in articles above a certain concentration. Moreover, hazardous chemicals may also be regulated through product-specific legislation such as the Restriction of Hazardous Substances (RoHS) Directive (2011/65), the Toys Directive (2009/48), the Regulation on Food Contact Materials (1935/2004), and the Regulation on Cosmetic Products (1223/2009). In addition to European legislation, there may be national rules, e.g., the Danish Executive order (BEK no. 947 of 20/06/2020) prohibits phthalates in toys and childcare articles intended for children aged 0-3 years. As a starting point, the same legal requirements apply to the chemical content in products made from recycled plastic and virgin plastic, respectively. As many of the restrictions entered into force recently (i.e., less than 10 years ago) there are still many products on the market which can be expected to contain hazardous substances, depending on the products’ lifetime in the use phase. Also, not all hazardous substances are regulated in all product groups, and as mentioned in section 2.3.1, hazardous substances may also form during the life cycle of plastic products.

Hence, recycling of plastic products is challenged by their potential content of hazardous substances, which needs to be addressed either by separating the hazardous substances from the plastic fraction (examples are described in the following paragraphs), or by applying the recycled plastic polymers for purposes where the specific hazardous substances are not regulated.

The recycling process typically starts with a sorting step, depending on the regarded waste stream. For WEEE and ELV certain parts are separated such as batteries, printed circuit boards, cooling gasses of e.g., fridges, bumpers, and fuel tanks. This is done to separate high value items, mitigate risks (e.g., fire hazard from batteries) or to satisfy legal demands (e.g., cooling gasses), but also to create homogenous waste streams for high quality recycling (Potrykus et al., 2024). A similar process is applied to plastic packaging waste, i.e., paper and glue is separated from the plastic fraction through a series of washing steps (Dehoust et al., 2021).

The resulting waste fraction is then typically shredded using various shredding techniques creating a mixed fraction consisting of plastic, metals, glass, and other materials present in the waste. This fraction then needs to be further separated. Most commonly, it is separated first via a density separation, whereby the denser particles sink to the bottom and the light particles float to the top (Andersson et al., 2019). This way, metals, glass, and certain plastics can be separated. Plastics such as polycarbonate (PC) and polyvinyl chloride (PVC) have a higher density than for example PE, PP and PS and can be separated with this method. Similarly, plastics containing additives, especially brominated flame retardants, have a higher density and sink to the bottom, however, not all can be separated with this method (Potrykus et al., 2024). The metals are sorted out from the heavy fraction via magnets and eddy currents and the remaining plastics are typically sent to incineration. The light fraction is further separated into the individual plastic polymers with further density separation and sensor-based separation. Such separation is based on the different physiochemical properties of the individual plastic polymers such as e.g., ultraviolet (UV) or infrared (IR) absorption, density, electrical conductivity, and colour (Strobl et al., 2021). The output of the recycling process are plastic flakes sorted by polymer type.

Limited information about possible contamination of plastic waste fractions during sorting and recycling was available from the stakeholder consultation and literature review. Pivnenko et al. (2016) found that household waste plastics can be contaminated by other high-phthalate articles such as PVC, potentially leading to a contamination of recycled plastics as achieving complete purity in sorting household waste is practically impossible. The issue of cross-contamination of waste fractions during recycling is also emphasized by Brosché et al. (2021, IPEN report on contamination of recycled plastic) as a challenge for recyclers, however, no further details are provided.

As compliance with EU legislation on chemicals (e.g., REACH, POP, RoHS etc.) needs to be ensured, the recycled batches of plastics are monitored using chemical analysis targeted for detecting regulated substances. The analysis shall be performed by the actor who needs to ensure the end-of-waste criteria set out in Article 6.1 of the Waste Framework Directive (2008/98/EC).

X-ray fluorescence scanners can quickly provide the concentration of a certain element in the sample and can thus be used to ensure compliance with EU law. For example, cadmium, lead, or zinc originating from the addition of stabilisers or antioxidants can be documented (Eriksen et al., 2018). Elements can also be used as indicators for other substances, e.g., bromine is commonly analysed to check for brominated flame retardants (Potrykus et al., 2024). For example, hexabromocyclododecane has a waste limit value of 500 mg/kg in the POP

Regulation and a molar mass of 641 g/mol, 75% of which is bromine. As such, if the recycled plastic has a bromine concentration of below 375 mg/kg compliance with the POP limit value is still ensured, even though no information about a specific compound is obtainable with XRF-analysis. More in-depth analysis is typically performed via gas or liquid chromatography coupled with a mass spectrometer (GC-MS and HPLC-MS, respectively) (Weber, 2017). Both methods provide information about the compounds present in the sample. Moreover, a stakeholder informed, that inductively coupled plasma analysis coupled to a mass spectrometer (ICP-MS) can be used for analysis of metal content.

Supply chain actors (collectors, recyclers and/or compounders) of recycled plastics interviewed during the stakeholder consultation report that the primarily recycled polymers are PE, PP, PS, ABS, PET, nylon and – to a lesser degree – PVC.

According to information from recyclers, the methods and frequency of chemical analyses of the recycled batches are highly varying and depend on the recycled waste stream, the recycler's practice, and the customer's requirements. Based on the experience of the operator and the input waste, the recycler estimates whether an output has a high chance of containing hazardous substances thus requiring analysis. One manufacturer of recycled plastic articles in the stakeholder consultation states that they themselves analyse the recycled plastic from PCR used as input material for production, since the quality of the recycled material varies by batch.

According to communication with stakeholders, both post-industrial and post-consumer plastics are recycled, however PIR plastic is easier to recycle due to its high purity and known composition. PIR plastic can be received from the hygiene, food production, building or pipe industry, while PCR plastic may originate from household waste, recycling stations, and manufacturers who have a take-back agreement with their customers.

A Danish compounder stated in the stakeholder consultation that 30-40% of their produced volume is PIR, however, the fraction of PCR is increasing due to increased focus on resources and sustainability. A Danish recycler reports that 95% of their production is based on PCR plastics (primarily from packaging), and only 5% originate from PIR. Another recycler providing recycled plastic material for furniture and other products informed that their production is entirely based on PCR.

2.3.1.6 Re-compounding

Upon drying, the flakes are re-compounded into pellets and sold to manufacturers.
Moulding and extrusion are key processes in this step, which usually involves operating temperatures of 200-300 °C. In this temperature, a range of hazardous substances (e.g., PBDE, VOC as residual monomers, phthalates, and PAH) may be released (Hahladakis et al., 2018).

Stakeholders inform that during the re-compounding heat stabilizers and antioxidants may be added to the recycled plastics to enable reheating of the material and enhance its lifetime, respectively. Examples of stabilisers and antioxidants mentioned by stakeholders include Irganox 1010 (tetrakismethylene-(3,5-di-t-butyl-4- hydroxyhydrocinnamate) methane) and Irgafos 168 (tris (2, 4-di-tert-butylphenyl) phosphite). Moreover, calcium stearate may be added to bind dust formed during the process. Stakeholders also mention that odour is typically not a problem in PIR plastics, hence substances to account for bad odour (odour maskers) are usually not added. Depending on the need of the customer, other additives, for example colours, may be added. For black colouring, carbon black is used, while titanium dioxide is applied for white colouring. However, stakeholders inform, that due to growing awareness of introducing fewer substances to the plastic, the customer demand for coloured pellets has decreased.

The re-compounding is either performed by the recycler themselves or by a specialised compounder. The re-compounding step ensures a homogenous product and can also be used to filter out any leftover impurities such as non-melting plastics and parts of printed circuit boards (Andersson et al., 2019). Which waste fractions and plastics are recycled and re-compounded, depends on the market situation and the recyclers/compounders specialisation; for example, one recycler/compounder informed that they only process PP and PE.

According to the communication with stakeholders, there are no standardised requirements regarding chemical analyses or frequency of analyses on the flakes. A Danish compounder informs that all the received sorted material (flakes or post-industrial waste) originates from EU and is therefore usually anticipated to be compliant with REACH. In some cases, additional information is available. Often, a declaration of compliance, stating that the sorted material complies with REACH, is provided by the supplier to the compounder. For PIR material, SDS may be provided by the supplier. Additionally, analyses may occasionally be conducted (two-three times a year) on materials where less purity is anticipated e.g., flakes originating from household waste.

Whether chemical analyses on the pellets are conducted and if, how often, depends on the buyer of the recycled plastic pellets. A compounder states that for recycled plastic for use as cosmetics packaging or furniture, every batch of pellets is tested. Furthermore, the same stakeholder mentions that there is no difference between PIR and PCR regarding the chemical analysis, which is also why PIR and PCR plastics are sometimes sold in mixed batches.

None of the compounders interviewed during the stakeholder consultation indicated, that their recycled plastic pellets are sold for food contact materials, toys, or medical and pharmaceutical applications.

For the recycled plastic pellets, a SDS is created and provided to the customer. The SDS informs the buyer that the plastic is made from recycled waste and must also include added hazardous additives and leftover hazardous substances from the first use if present above a certain concentration threshold.

2.3.1.7 Manufacturing and retailing of new articles of recycled plastics

In a last step, a manufacturer uses the recycled plastics to produce new articles. The plastic article is sold either business-to-business (B2B) or business-to-consumer (B2C) through a retailer.

The manufacturer’s choice of whether to include recycled plastics in the articles depends on the quality of the recycled plastic available as well as on the application of and legal requirements to the articles. For example, recycled plastics are commonly used in sandwich structures in packaging, where the recycled plastic in the middle is covered by a layer of virgin plastic on the outside (Jiang et al., 2020).

According to interviewed manufacturers, PP, PE, and PET polymers are the most used polymers for producing recycled plastic consumer articles. In some cases, the polymers are sourced outside the EU. If a manufacturer or retailer demands documentation of the plastic product being compliant with REACH or even requires documentation of the content of SVHC or heavy metals, a batch-specific declaration can be made upon chemical analysis conducted by either the compounding company or its suppliers. This declaration can be passed on to the manufacturer or retailer for documentation purposes. A Danish recycler notes that the price of the recycled plastic pellets is affected by the number of extra analyses and certificates required by the customer. Of the five manufacturers and/or retailers, who responded in the stakeholder consultation, only three state that they conduct additional quality assurance in terms of chemical analyses. The manufacturers mention that technical properties e.g., tensile strength of the recycled plastic is of higher concern than chemical composition. One of the contacted manufacturers relies on the tests for the EU Ecolabel certification to document the absence of potentially hazardous substances.

Limited information was available on which additives are added in the manufacturing process of consumer articles made of recycled plastic. One manufacturer informed that calcium is added to improve the technical and fire-resistant properties of the recycled plastic.

2.3.2 Consumer articles made of recycled plastics

2.3.2.1 Articles made of recycled plastic which children can be exposed to

Consumer articles on the Danish market were identified from websites of a Danish general consumer goods retailer, children's fashion retailers, home décor and homeware retailers, and several toy retailers (in total, 20 Danish retailers). It is noted that these retailers provide Danish web shops, but some of them also operate in other European countries or globally. Additionally, relevant products from two international online marketplaces, one EU décor retailer and one EU furniture retailer were added to the product list (four additional retailers).

In total, 62 articles were listed comprising childcare articles, furniture, home textiles and interior, textiles for children's clothing and toys (TABLE 2-2). All listed articles were claimed to be made of recycled materials on the retailer's websites.

TABLE 2-2. Number of identified articles of recycled plastic and examples of articles within each article category in focus.

Article category	Number of articles	Examples of articles
Furniture	8	Chairs, stool, table
Home textiles and interior	11	Pillow, blanket, sponge, cloth, towel, rubber flooring[1], foam mat
Textiles for clothing	8	Coats, pants, swimwear, jumpsuit
Childcare articles	17	Baby nest, changing pad, nursing pillow, safety rail for chair, teething ring, toilet seat, toothbrush
Toys	18	Toy bear, truck, play rug, bike, play sword, games
Total	**62**	

[1] Strictly not a textile, but included in this category as a flooring article

2.3.2.2 Polymers of consumer articles made of recycled plastic

For about one third of the articles (19/62), it was not specified which recycled plastic type (polymer) the articles consisted of TABLE 2-3. Of the articles for which the recycled polymer was specified, the most abundant types were PET and polyester (app. 42% of all articles). Polyester is a general term for polymers containing an ester functional group in every repeated unit of their main chain. The most common polyester is PET, and sometimes the terms PET and polyester are used as synonyms (PET Europe, 2024). Other common polymers in recycled plastic articles comprise PP (app. 10%) and PE (app. 5%). Only a few articles were advertised to be made from recycled PUR (polyurethane), PS, or PES (polyethersulfone).

TABLE 2-3. Number of identified articles of recycled plastic made from the respective polymers, HDPE, LDPE, LDPET, PES, PET, polyester, PP, PS, PU, other or non-specified polymers.

Polymer	Childcare article	Furniture	Home textiles and interior	Textiles for clothing	Toys	Number of articles per polymer
HDPE		1			1	**2**
LDPE					1	**1**
LDPET					1	**1**
PES				1		**1**
PET	7		3	1	2	**13**
Polyester	4	1	2	4	2	**13**
PP	3			1	2	**6**
PS		1			1	**2**
PU				1		**1**
Other	1[b]	2[a, c]				**3**
Not specified	2	3	5	1	8	**19**
Number of articles per category	**17**	**8**	**11**	**8**	**18**	**62**

[a] One article made of Ecothylene®. Composition of polymer not specified at the manufacturer's homepage (Ecobirdy). Based on name and application, presumably a HDPE material.

[b] Copolyester Tritan Renew (copolyester made by molecular recycling technology containing up to 50% certified recycled content according to the polymer manufacturer Eastmen)

[c] One of either or a combination of PS, PP, PC, PETG (polyethylene terephthalate glycol-modified), ABS, and/or PLA (polylactic acid)

2.3.2.3 Origin of recycled plastic used for consumer articles (PIR/PCR)

The country of manufacture is within Europe for the majority of the articles (48 articles). For six articles, the country of manufacture is stated to be outside Europe (India, Thailand, USA) and for the remaining eight articles, the country of manufacture is not stated. It is noted that the country of manufacture of the articles only to a limited degree indicates the source of the recycled plastic (i.e., recycled plastic for manufacture of articles in the EU may be sourced from non-EU countries).

With respect to the origin of the recycled plastic used for consumer articles, information was provided on whether the recycled material originated from PCR or PIR plastic for about half of the articles (TABLE 2-4). Of these, most articles were indicated to be made of PCR plastic (24 articles) stemming from PET bottles, or unspecified polymers from household waste or marine waste. Only six articles were claimed to originate from PIR plastic. Articles made of PIR PS and PP were manufactured outside of the EU and sold through EU retailers (overview of data on countries of manufacturers and retailers not shown), which may indicate that the source of recycled PIR plastic was outside of the EU. For the remaining articles (32 articles), the origin of the recycled plastic was not specified.

It is noted that there is uncertainty related to the figures about the origin of the recycled plastic as the information is based on information available from the retailers. Claiming that the plastic is recycled from post-consumer sources is actively used in the promotion of some articles, whereas fewer articles are advertised as being produced from PIR plastic. Also, some articles may contain recycled plastic (as indicated by content of e.g., flame retardant at levels below functionality, see section on flame retardants in 2.3.3), but are not advertised as such. Articles not marketed as containing recycled plastic were not identified in the search method of the survey.

TABLE 2-4. Origin and polymer of articles**.**

Origin	Polymer	Number of articles	Note on origin
PCR	*All polymers*	*24*	
	HDPE	2	-
	LDPE	1	-
	Not specified	9	From marine waste, household waste or bottles
	PET	9	Mostly from bottles
	PP	3	-
PIR	*All polymers*	*6*	
	NA	2	-
	PET	1	-
	PP	1	Article manufactured in Asia
	PS	2	Articles manufactured in Asia
Not specified	*All polymers*	*32*	
	LDPET	1	-
	Not specified	8	One article (rubber tile) made from recycled rubber tire
	PES	1	-
	PET	3	-
	Polyester	13	-
	PP	2	-
	PU	1	-
	Other	3	-
Total		**62**	

Based on the findings of the survey on consumer articles made from recycled plastic, PET appears to be the most common polymer type used for consumer articles made from recycled plastic. Moreover, the survey shows that PCR plastic is more frequently used in consumer products compared to PIR plastic. However, for the majority of the consumer products (app. 52%) the source of the recycled plastic is not specified. It is also noted that the presented product inventory (62 articles from 24 retailers) does not provide an exhaustive list of articles available but presents a selection of articles available to Danish consumers.

2.3.3 Hazardous substances in consumer articles made of recycled plastics

The presence of harmful substances in consumer articles made of virgin plastic is relatively well-investigated, and the Danish EPA also published a long list of publications on this matter[6].

Potentially, recycled plastic products may contain the additives for the following reasons:

- Same additives as in virgin plastic products, added for functional reasons (or present as impurities)
- Additives stemming from recycled plastics, with no use intention in the recycled plastic products (potentially legacy additives)
- Additives to enable the use of recycled plastic fractions, e.g., heating stabilizers, odour maskers to cover over the smell of recycled plastic, or pigments to achieve colourisation of the recycled plastic.

The main purpose of this section is to provide an overview of the substance groups and substances that may be present in consumer articles made of recycled plastics, as well as to report their concentrations in consumer articles made of recycled plastics and/or recycled plastic materials that potentially could be used for consumer articles. To the extent the information is available from the publications, the origin of the hazardous substance in the recycled plastic as well as the polymer type is reported.

The section is structured according to chemical/functional groups of additives that were identified in the literature as occurring in consumer articles made of recycled plastic or in recycled plastic in general. Certain substances or substance groups, that earlier have been reported to be present in virgin plastic (e.g., certain blowing agents, organotin biocides etc. as listed in Hansen et al., 2014) are not listed here, as no information on their presence in recycled plastic was identified. This, however, does not mean that these substances do not occur in recycled plastic but merely that no information has been found about their presence in recycled plastic.

The following subsections also include information on the presence and function of the substances in plastics, their general regulation status with respect to hazard identification (CLP) and regulation of their use in articles relevant within this project. This information is provided on an overall level, as the purpose and scope of the review was not to provide exhaustive information on classification, hazard, and regulation data for the large number of single substances comprised by each substance group.

It is noted that no fixed definition of 'hazardous substance' is applied here. If a substance was identified as hazardous, harmful, of concern or similar in the identified literature sources, it is also recognised as hazardous in the current report.

2.3.3.1 Brominated flame retardants (BFRs)

Source of presence and function in plastics

BFRs are a group of chemicals used to reduce the flammability of materials. They are commonly added to plastics, textiles, and electronic equipment to prevent or slow the spread of fire (Ionas et al. 2014, Zuiderveen et al. 2020). These chemicals can thus be found in

[6] Examples are: Survey and risk assessment of chemicals from gaming equipment no. 191, April 2023; CMR Substances in Toys - Survey of chemical substances in consumer products No. 141, 2015; Survey and health assessment of phthalates in toys and other products for children - Survey of chemical substances in consumer products No. 139, 2015; Chemical substances in car safety seats and other textile products for children – Survey of chemical substances in consumer products No. 135, 2015; Hazardous substances in plastics - Survey of chemical substances in consumer products No. 132, 2014.

various consumer products such as electronics, furniture, and building materials. In products made from recycled plastics, there is a potential for the presence of BFRs due to the recycling of materials that originally contained these substances. Since recycled plastics can originate from a variety of sources, including electronics and other BFR-treated items, there is a risk that BFRs can be carried over into new products. This raises concern about human exposure to these potentially harmful chemicals through everyday items, as BFRs are associated with environmental persistence, bioaccumulation, and potential health risks such as endocrine disruption and neurodevelopmental effects (Zuiderveen et al. 2020).

Regulation and hazard information
Due to their hazardous properties, some flame retardants have already been phased out. They are regulated under various European laws, including the POP Regulation (2019/1021), the REACH Regulation (1907/2006), and the RoHS Directive (2011/65/EU).

Several brominated flame retardants are included in the Annex XIV (Authorization list) of the REACH Regulation (1907/2006), including hexabromocyclododecane (HBCD) and diasteroisomers, and decaBDE. Furthermore, Annex XVII (Restriction list) of the same regulation includes polybrominated biphenyls (PBB) (entry 8, restriction on the use in textile articles, such as garments, undergarments, and linen), and octaBDE (entry 45, not allowed to be used as a substance and limited at 0.1% by weight when used as a constituent of other substance or in mixtures). HBCD, HBB, and PBDEs are included in Annex 1 (Part A) and Annex IV of the POP Regulation (2019/2021). And lastly, RoHS Directive (2011/65/EU) restricts the use of PBB and PBDE at 0.1% in electric and electronic equipment.

While some BFRs are heavily restricted, novel BFRs such as TBBPA and derivates, brominated diphenyl ethyls (e.g., DBDPE) and brominated phthalates (e.g., bis(2-ethylhexyl) tetrabromophthalate) not regulated at European level. However, it is important to note that TBBPA and bis(2-ethylhexyl) tetrabromophthalate appear on the candidate list, which triggers compliance with Article 31 and Article 33 of the REACH Regulation (compare section 2.3.1.2 for provisions of the Articles in REACH).

Concentrations in articles and materials of recycled plastics
Several studies (DiGangi et al., 2017, Strakova et al., 2017, Strakova et al., 2018) investigated whether flame retardants found in electronic waste are carried into new consumer articles due to plastic recycling.

For instance, DiGangi et al. (2017) analyzed the presence of octaBDE, decaBDE, and HBCD in Rubik's cubes, along with several other types of plastic toys. Laboratory analysis of 95 Rubik's cubes and 16 other items such as thermo cups, hair clips, combs, headdresses, and children's toys from 26 countries (both European and non-European), revealed significant contamination with BFRs. In products purchased in European countries, octaBDE was detected in concentrations ranging from 1 to 210 mg/kg, HBCD in concentrations ranging from 0 to 375 mg/kg and decaBDE in concentrations from 0 to 400 mg/kg. It is relevant to note that significantly higher concentrations were measured in consumer articles purchased in non-European countries, e.g., octaBDE up to 1174 mg/kg in Nigeria, decaBDE up to 672 mg/kg in Nigeria and HBCD up to 1586 mg/kg in Argentina.

A similar investigation was conducted by Strakova et al. (2018) where a total of 430 plastic items, including toys, hair accessories, kitchen utensils, and other consumer products, were purchased in stores and markets across European Union Member States as well as surrounding Central Eastern European Countries between April and July 2018. The authors explain the focus was on consumer products with black components as potential indicators of recycled e-waste plastic. After initial screening of products for bromine content, 109 out of the 430 collected items were chosen for further targeted analysis of PBDEs, HBCD, and novel

BFRs, i.e., 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), (OBIND), 2,3,4,5,6-pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT). The limit of quantification (LOQ) ranged between 0.0005 to 0.005 mg/kg for PBDEs, between 0.0005 to 0.010 mg/kg mg/kg for novel BFRs and was 0.010 mg/kg for HBCD. The investigation found that 94 samples (86%) contained octaBDE with concentrations ranging from 1 to 161 mg/kg, while 100 samples (92%) contained decaBDE, with concentration ranging from 1 to 3318 mg/kg. 45 samples (41%) had HBCD concentrations ranging from 1 to 207 mg/kg, while 99 samples (91%) contained at least one type of the novel BFRs.

The authors concluded that presence of BFRs in examined samples most likely originates from recycled electronic waste. This conclusion arises from the fact that the tested children's toys, hair accessories, and kitchen utensils do not require fire resistance, and the concentrations detected were lower than those necessary to achieve fire resistance in products such as electronic plastic casings, which typically need 7-20% of weight (70,000 – 200.000 mg/kg) from PBDEs commercial mixtures to meet the flammability standards (Strakova et al., 2018).

More detailed information on the concentrations of detected BFRs and product types in which the substances were detected is provided in TABLE 2-5. None of the identified sources specified which polymer the toys are made of.

Additionally, Ionas et al. (2014) measured concentrations of PBDEs in children's toys (n=114). Some toys were donated by parents from Belgium, and some collected from a recycling park or bought on the flea market/toy store. In general, concentrations of measured BFRs were found to be rather low, indicating a low exposure potential for children using these toys. BDE-209 (also referred to as decaBDE) was a predominant congener, making up 99% of the total PBDEs detected. Three samples had significantly higher concentrations compared to others, with two of them originating from China and one from an unknown country. Two of these samples were produced before 2007 (with concentrations at 143 and 16 mg/kg) and one after (concentration of 19 mg/kg). The highest concentration of BDE-209 (143 mg/kg) was found in a toy consisting of a foam inner core and a textile cover. The authors observed that this concentration is one order of magnitude below the REACH threshold and insufficient to provide flame retardancy. Additionally, it was also observed that most of the BDE-209 was in the textile rather than the foam, likely because it was added to the textile's back coating. The study concluded that presence of PBDEs at these levels is likely to originate from recycled materials containing PBDEs. This conclusion is also supported with higher concentration levels in samples produced before 2007 and higher detection frequencies observed on samples produced after 2007.

The presence of BFRs particularly in recycled plastic was investigated by Andersson et al. (2019). The materials analyzed in the study were collected from several recyclers across Europe. A total of 54 materials were collected, comprising of 17 PS, 20 PP, 13 ABS, 3 PE, and 1 MEP[7]. These plastics originated from WEEE and/or ELV, including small and large domestic appliances, TVs monitors, fridges, and different types of ELV. However, the information of the exact type of product or part nor the information on the year of collection is not stated. The XRF screening showed that 47 out of 54 samples contained bromine which most likely originate from BFRs with the average content of 377 mg/kg. The highest average value of bromine content was observed in ABS at a concentration of 396 mg/kg, while the highest measured concentration of bromine was detected in PS. Additional analysis with the GC-MS revealed presence of PBDEs in 15 samples with 14 samples containing decaBDE and three

[7] Full name of the polymer not provided in the study. Possibly a misspelling of metallocene polyethylene which is usually abbreviated as mPE.

samples containing some combination of nona-, octa- and decaBDE. The average concentration of decaBDE was 19 mg/kg, and highest value 48 mg/kg. TBBPA was detected in 23 samples with an average concentration of 26.6 mg/kg and a maximum value of 78 mg/kg. DBDPE, commonly used as a replacement for decaBDE was detected in seven samples, however, quantitative information was not obtained due to material deterioration during sample preparation. The combination of the two analyses revealed that most bromine comes from the non-regulated compounds (also referred to as novel BFR, see FIGURE 2).

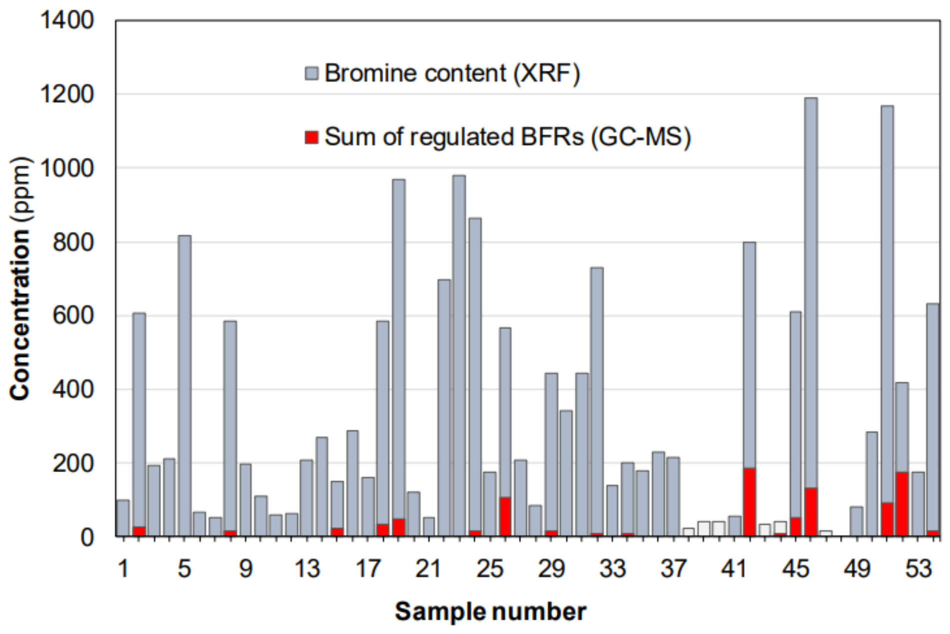

FIGURE 2. Data from bromine content from XRF (grey) compared to the sum of regulated BFRs (PBDEs and PBBs) measured by GC-MS (red). Light grey bars indicate values below LOQ of 50 mg/kg for XRF analysis method (Andersson et al., 2019).

TABLE 2-5. Brominated flame retardants identified in consumer products made of recycled plastic

Substance	Abbreviation	CAS No.	Product type	Number of samples	Concentration, mg/kg	Sampling location (year)	Information source(s)
octabromodiphenyl ether	octaBDE	32536-52-0	Rubik's cube	23	0-210	European Union countries	Di Gangi et al 2017, Strakova et al 2018
			Rubik's cube	74	0-1174	non-European Union countries	Di Gangi et al 2017, Strakova et al 2018
			Toy (various types of guns)	9	1-34	European Union countries (2018)	Strakova et al 2018
			Toy (car, Formula 1)	3	2-9	European Union countries (2018)	Strakova et al 2018
			Toy (various types of cars)	10	1-35	non-European Union countries (2018)	Strakova et al 2018
			Toys (various types, e.g., telescope, fidget cube, chess tray, small guitar, water game, magic cube etc.)	12	<LOQ - 161	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as hairbrush, diadem, hair clip, hair claws, comb)	30	<LOQ-50	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as diadem, hair clip, hair claws, comb, hair wreaths set)	12	<LOQ-70	non-European Union countries (2018)	Strakova et al 2018
			Massage roller	1	42	Germany (2018)	Strakova et al 2018
			Waste bin	1	13	Germany (2018)	Strakova et al 2018
decabromodiphenyl ether	decaBDE	1163-19-5	Rubik's cube	23	0-400	European Union countries	Di Gangi et al 2017, Strakova et al 2018

Substance	Abbreviation	CAS No.	Product type	Number of samples	Concentration, mg/kg	Sampling location (year)	Information source(s)
			Rubik's cube	74	0-672	non-European Union countries	Di Gangi et al 2017, Strakova et al 2018
			Toy (various types of guns)	9	3-1043	European Union countries (2018)	Strakova et al 2018
			Toy (car, Formula 1)	2	33-118	European Union countries (2018)	Strakova et al 2018
			Toy (various types of cars)	11	4-1170	non-European Union countries (2018)	Strakova et al 2018
			Toys (various types, e.g., telescope, fidget cube, chess tray, small guitar, water game, magic cube etc.)	16	<LOQ-3318	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as hairbrush, diadem, hair clip, hair claws, comb)	32	<LOQ-2491	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as diadem, hair clip, hair claws, comb, hair wreaths set)	13	<LOQ-1494	non-European Union countries (2018)	Strakova et al 2018
			Massage roller	1	178	Germany (2018)	Strakova et al 2018
			Waste bin	1	165	Germany (2018)	Strakova et al 2018
hexabromocyclododecane	HBCD	3194-55-6	Rubik's cube	23	0-42	European Union countries	Di Gangi et al 2017, Strakova et al 2018
			Rubik's cube	74	0-1586	non-European Union countries	Di Gangi et al 2017, Strakova et al 2018
			Toy (various types of guns)	6	1-8	European Union countries (2018)	Strakova et al 2018
			Toy (various types of guns)	2	1-8	non-European Union countries (2018)	Strakova et al 2018

Substance	Abbreviation	CAS No.	Product type	Number of samples	Concentration, mg/kg	Sampling location (year)	Information source(s)
			Toy (various types of cars)	7	<LOQ-10	non-European Union countries (2018)	Strakova et al 2018
			Toys (various types, e.g., telescope, fidget cube, chess tray, small guitar, water game, magic cube etc.)	11	<LOQ - 25	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as comb, hairbrush, diadem, hair clip, hair claws)	20	<LOQ-207	European Union countries (2018	Strakova et al 2018
			Hair accessories (including products such as comb, hair clip, hair wreaths set)	10	<LOQ-94	non-European Union countries (2018)	Strakova et al 2018
			Massage roller	1	<LOQ	Germany (2018)	Strakova et al 2018
			Waste bin	1	<LOQ	Germany (2018)	Strakova et al 2018
Sum of novel BFR	ΣnBFRs*		Toy (various types of guns)	10	<LOQ-89	European Union countries (2018)	Strakova et al 2018
			Toy (various types of guns)	2	27-57	non-European Union countries (2018)	Strakova et al 2018
			Toy (car, Formula 1)	2	9-18	European Union countries (2018)	Strakova et al 2018
			Toy (various types of cars)	11	<LOQ-119	non-European Union countries (2018)	Strakova et al 2018
			Toys (various types, e.g., telescope, fidget cube, chess tray, small guitar, water game, magic cube etc.)	15	<LOQ - 1076	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as hairbrush, comb, diadem, hair clip, hair claws)	33	<LOQ-161	European Union countries (2018)	Strakova et al 2018
			Hair accessories (including products such as comb, diadem, hair clip, hair claws, hair wreaths set)	12	<LOQ-289	non-European Union countries (2018)	Strakova et al 2018

Substance	Abbreviation	CAS No.	Product type	Number of samples	Concentration, mg/kg	Sampling location (year)	Information source(s)
			Massage roller	1	160	Germany (2018)	Strakova et al 2018
			Waste bin	1	77	Germany (2018)	Strakova et al 2018

* Sample contains at least one of the following substances: 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), decabromodiphenyl ethane (DBDPE), hexabromobenzene (HBB), octabromo-1,3,3-trimethylphenyl-1-indan (OBIND), 2,3,4,5,6-Pentabromoethylbenzene (PBEB), and pentabromotoluene (PBT). Exact substance is not specified.

2.3.3.2 Organophosphorus flame retardants (halogenated or non-halogenated)

Source of presence and function in plastics

Organophosphorus flame retardants (OPFRs) are a group of chemicals containing phosphorous-based groups, commonly used to enhance fire resistance of materials, and thus added to various consumer products such as textiles, electronics, industrial materials, and furniture to prevent to risk of fire (Pantelaki and Voutsa, 2019). Unlike reactive flame retardants (e.g., PBDE and TBBPA) that are chemically bonded to materials, OPFRs are considered additive flame retardants, making them more likely to leach into the environment (Yao et al., 2021). They can lead to exposures in the indoor environments through processes such as abrasion, volatilization, and direct contact migration from products (Song et al., 2024). These compounds are also used as plasticizers, antifoaming or anti-wear agents in lacquers, hydraulic fluids, and floor polishing agents (Pantelaki and Voutsa, 2019).

The group can be subdivided in halogenated and non-halogentaged OPFRs. Common substances within the non-halogenated OPFRs are triethyl phosphate (TEP; CAS no. 78-40-0), diethyl ethyl phosphonate (DEEP; CAS no. 78-38-6), tricresyl phosphate (TCP; CAS no. 1330-78-5), and triphenyl phosphate (TPP; CAS no. 115-86-6), while examples of the halogenated (chlorinated) OPFRs are tris(2-chloroethyl) phosphate (TCEP; CAS no.115-96-8), tris(2-chloro-1-methylethyl) phosphate (TCPP; CAS no. 13674-84-5), and tris[2-chloro-1-(chloromethyl)ethyl] phosphate (TDCP; CAS no. 13674-87-8).

Regulation and hazard information

Some OPFRs are limited or prohibited in the EU. For example, presence of TCEP, TCPP and Tris(1,3-dichloro-2-propyl) phosphate (TDCPP) is limited to 5 mg/kg in toys intended for use by children under 36 months or in toys intended to be placed in the mouth (Toy Safety Directive 2009/48/EC). Furthermore, REACH restricts the use of tris(2,3-dibromopropyl) phosphate (CAS No.: 126-72-7) in textile articles, such as garments, undergarments, and linen, intended to come into contact with the skin. Furthermore, TCEP and tryxylyl phosphate are included in the Annex XIV of REACH (“Authorization list), meaning the companies that want to continue using these substances must prepare an application for authorization, otherwise they cannot continue using it.

Some of the halogenated OPFRs (TCEP, TCPP, TDCP) are recognized as carcinogenic, mutagenic or toxic to reproduction (CMR substances) in childcare articles (ECHA, 2023a).

Concentrations in articles and materials of recycled plastics

De Jonker et al. (2023) measured additives in various plastic consumer products, including children’s toys. The analysis of children’s toys, namely a toy cube, toy car, black toy cat and toy cowboy gun, revealed presence of OPFRs, including TBOEP, TPhP/DPP, RDP (resorcinol bis(diphenyl) phosphate), BDP, methyl-, bis[(5-ethyl-2-methyl-2-oxido1,3,2-dioxaphosphorinan-5-yl)methyl], and butyl diphenyl phosphate (concentrations were not provided as the OPFRs were detected in a non-quantitative screening method). The authors concluded that the presence of OPFRs and BFRs in analyzed samples might come from a recycled fraction of WEEE which may lead to exposure of children. However, further quantifications are needed as there is no information on the manufacturing year of analyzed toys and study was performed on randomly chosen consumer products and not on the ones which contain a certain share of recycled plastic. Additionally, it is important to note that the study used an analytical method that only tentatively identified OPFRs in the screened products (AP-MALDI in positive ionization mode), meaning that the identification is only preliminary and not yet confirmed. This implies that the detected compounds have been identified based on their mass spectra, but further validations are needed to confirm their identities.

Ionas et al. (2014) measured concentration of several OPFRs in children's toys (n=114) with some of them donated by parents from Belgium, some collected from a recycling park or bought on the flea market/toy store. The concentrations of phthalates and OPFRs were found to be significantly higher compared to those of PBDEs. More specifically, tris(2,3-dibromopropyl) phosphate (TDBPP) was not detected in any of the analyzed samples, while TCEP followed the same trend as PBDEs. On average, concentration levels of OPFRs were 3 orders of magnitude higher than PBDEs, and their detection frequencies were also higher (in the range of 10-52% compared to range of 2-19% for PBDEs). The most frequently detected OPFRs were tris(2,3-dibromopropyl) phosphate (TEHP) and TPhP, both with a detection frequency of 52%. TEHP is used as a flame retardant, plasticizers, and solvent in some industrial processes. TEP was detected with a median concentration of 3 mg/kg, a 90th percentile of 17 mg/kg, and a maximum concentration of 20 mg/kg. However, its recoveries were low and fluctuating, as it was the most volatile compound targeted in the study. While a decreasing trend was observed for toys produced after the REACH regulation went into effect, detected low residual levels combined with an increase in detection frequencies indicate that this contamination might arise due to the recycling of the raw materials used in toy manufacturing.

Andersson et al. (2019) investigated the presence of several substances in recycled plastic, including tris(2-chloroethyl) phosphate (TCEP), an OPFR also commonly used as a plasticizer to make plastics softer and more flexible. The materials analyzed in the study were collected from recyclers across Europe. A total of 54 materials were collected, comprising of 17 PS, 20 PP, 13 ABS, 3 PE, and 1 MEP. These plastics originated from WEEE and/or ELV, including small and large domestic appliances, TVs monitors, fridges, and different types of ELV. However, the study did not specify the exact type of product or part nor the year of collection. Results showed that none of analyzed samples (n=4) contained TCEP above the LOQ of 100 mg/kg.

In conclusion, the reviewed studies did not provide conclusive evidence that the detected OPFRs originate from recycled plastic. The increased use of OPFRs is primarily due to stricter regulations and bans on the use of certain BFRs, such as PBDEs, due to their environmental persistence and potential health risks. While some OPFRs can occur intentionally in the consumer articles as a replacement for some regulated flame retardants, it cannot be excluded that there are also substances belonging to this group that occur as impurities from recycled plastic, especially if detected at low concentrations which are insufficient to provide flame retardancy properties.

2.3.3.3 Phthalates

Source of presence and function in plastics

Phthalates are a group of chemical compounds commonly used as plasticizers to increase the flexibility, transparency, durability, and longevity of plastics. These substances are widely found in various consumer products, including those made from recycled plastic. The presence of phthalates in plastic items is of particular concern, as the substances are not chemically bound and can be more easily leached from plastic products over time. Bis(2-ethylhexyl)phthalate (DEHP) is an example of a previously commonly used plasticizer in PVC and other brittle plastics such as PS (Andersson et al 2019). In 2020, DEHP was restricted in articles in concentrations > 0.1%, with a few industrial exceptions.

Regulation and hazard information

The REACH Regulation (EC) No 1907/2006 restricts the presence of DEHP (CAS No.: 117-81-7), dibutyl phthalate (DBP) (CAS No.: 84-74-2), benzyl butyl phthalate (BBP) (CAS No.: 85-68-7), and diisobutyl phthalate (DIBP) (CAS No.: 84-69-5) to 0.1% by weight in articles, including all toys and childcare articles. It also restricts di-n-octyl phthalate (DNOP) (CAS No.:

117-84-0), di-‘isononyl’ phthalate (DINP) (CAS No.: 28553-12-0), and di-‘isodecyl’ phthalate (DIDP) (CAS No.: 26761-40-0) to the same percentage in toys designed for mouthing.

Both DEHP, DBP, BBP as well as four additional phthalates (1,2-benzenedicarboxylic acid, dipentylester, branched and linear; n-pentyl-isopentylphthalate; di-n-pentyl phthalate; diisopentylphthalate) have a harmonized classification as reprotoxins (Repr. 1B) under the CLP Regulation (1272/2008).

In June 2020, the Danish Ministry of the Environment and Food issued a new Executive order on the prohibition of phthalates in toys and articles for young children[8], which applies to children aged 0-3 years. According to this Executive order, use of phthalates is prohibited in toys and articles for young children or their parts, in concentrations above 0.05% by mass. It also bans import or sale of such toys and articles or their parts containing phthalates in the same concentration limit.

Concentrations in articles and materials of recycled plastics

Ionas et al. (2014) measured concentration of several phthalates in children’s toys (n=49) with some of them donated by parents from Belgium, some collected from a recycling park or bought on the flea market/toy store. The concentrations of phthalates and organophosphorus flame retardants were found to be significantly higher compared to those of PBDEs. DEHP was the most frequently detected phthalate, with a detection frequency in the range of 88-100%. DBP had a similar detection frequency range but was less commonly found in hard and soft plastic. DEP and BBP were also frequently detected, with detection frequencies ranging from 63% to 100% for DEP and 52% to 100% for BBP. The highest concentrations of phthalates detected in various types of toys were as follows: DMP was found at 25 mg/kg in toys made of soft plastic, DEP at 250 mg/kg in toys made of hard plastic, DBP at 6,200 mg/kg in toys made of hard plastic, DEHP at 686,000 mg/kg in toys made of hard plastic, BBP at 1,900 mg/kg in toys made of foam and textile, DPP at 1 mg/kg in toys made of hard and soft plastic. DNOP was detected only in toys made of foam and textile in concentrations up to 4 mg/kg. Out of all 49 samples, only five contained phthalates exceeding limit of 0.1% (1000 mg/kg). The authors explain that many of the samples displayed phthalate concentrations too low to significantly alter material properties, indicating that their presence might not have been purposefully introduced but could stem from the use of recycled materials or cross-contamination during manufacturing processes.

Pivnenko et al. (2016) measured selected low molecular weight (LMW) phthalates (DMP, DEP, DPP, DiBP, DBP, BBzP, DEHP, DCHP and DnOP) in samples of household plastics, as well as in recycled and virgin plastics. The aim was to evaluate whether the source of plastics (waste, recycled, or virgin) has an influence on the phthalate content in the collected samples. Samples of residual (RWP) and source-segregated (SSWP) waste plastics were collected from a municipality in Southern Denmark in April 2013, covering 100 single-family households. To supplement the household waste samples, processed plastic samples were collected from industry. These included recycled household (RHP) and PIR[9], as well as virgin plastics (VP), sourced directly from recyclers and producers in China, Denmark, Germany, and the Netherlands. In total, 20 waste samples (13 RWP and 7 SSWP), 20 recycled samples (9 RHP and 11 RIP), and 8 VP samples were collected and analyzed. Based on the obtained results TABLE 2-6 the authors concluded that there is no significant difference in phthalate content between RWP and SSWP, indicating that collected household plastics did not affect phthalate content. Similar phthalate content in RWP and SSWP and RHP suggest that phthalates are not removed during recycling and may persist and accumulate in recycled plastics. Furthermore,

[8] BEK no 947 of 20/06/2020: Executive Order on the Prohibition of Phthalates in Toys and Childcare Articles (retsinformation.dk)

[9] The source uses RIP as an abbreviation for post-industrial recyclate

no significant difference between RIP and VP indicates that recycling industrial waste does not significantly increase phthalate content. And lastly, the significant difference between RWP, SSWP, and RHP, RIP and VP suggests that phthalates might be added during later manufacturing stages (such as labeling and gluing) or that household waste plastics are contaminated by other high-phthalate articles such as PVC. This contamination could spread to recycled plastics, as achieving complete purity in sorting household waste is practically impossible (Pivnenko et al., 2016).

TABLE 2-6. Concentration range (min-max, mg/kg) of measured phthalates in the samples of plastics (Pivnenko et al., 2016).

Sample*	DMP	DEP	DPP	DiBP	DBP	BBzP	DEHP	DCHP	DnOP
LOD	0.077	3.4	0.036	0.20	0.094	0.022	0.43	0.16	0.20
DF	19	11	14	86	93	36	79	4	20
RWP	<LOD-120	<LOD-150	<LOD-4.3	<LOD-460	<LOD-190	<LOD-92	<LOD-860	<LOD-0.72	<LOD-99
SSWP	<LOD-0.54	<LOD-5.5	<LOD-0.36	<LOD-23	<LOD-360	<LOD-1.1	<LOD-2700	<LOD	<LOD-2.0
RHP	<LOD-3.4	<LOD-6.3	<LOD	<LOD-23	<LOD-11	<LOD-15	<LOD-600	<LOD-2.5	<LOD-31
RIP	<LOD-0.22	<LOD-19	<LOD-0.47	<LOD-7.1	<LOD-12	<LOD-0.36	<LOD-17	<LOD	<LOD-0.38
VP	<LOD	<LOD-5.3	<LOD-0.44	<LOD-4.8	<LOD-15	<LOD-0.21	<LOD-21	<LOD-0.34	<LOD-7.5

Abbreviations: LOD: Limit of detection, DF: detection frequency, RWP: residual waste plastics, SSWP: Source-segregated waste plastics, RHP: Recycled household plastics, RIP: Recycled industrial plastics, VP: Virgin plastics

The presence of phthalates in recycled plastic was also investigated by Andersson et al (2019). For this study, various types of plastic materials were collected from recyclers across Europe. These plastics originated from WEEE and/or ELV, including small and large domestic appliances, TVs monitors, fridges, and different types of ELV. A total of 54 materials were collected, comprising of 17 PS, 20 PP, 13 ABS, 3 PE, and 1 MEP, however, phthalates were only investigated in the PS samples with DEHP being detected in 10 out of 16 samples of PS, and with concentrations reaching up to 300 mg/kg and an average value of 140 mg/kg. Other phthalates were not detected in the PS samples.

The reviewed studies indicate that the presence of phthalates in consumer products likely originates as impurities from recycled plastic materials, without intentional use in the recycled plastic products, especially for the phthalates that are regulated under REACH.

2.3.3.4 Metals

Source of presence and function in plastics

Presence of metals in plastic material can occur due to several reasons. They can be intentionally added as part of an additive (Al, As, Cd, Co, Cr, Cu, Fe, Li, Pb, Sb, Ti, Zn), used as catalysts in the production (Sb, Ti, Cr, Hg, Mn) or added from contamination during use and waste management (Fe, Al, Cu, Mn, Zn, Ni) (Eriksen et al 2018). In the past, cadmium compounds were used both as stabilizers and pigments in various PVC products (both rigid and soft) and as pigments in other plastic materials such as PE, PP, PE-X, PUR. The use of cadmium compounds in PVC and other plastic materials ceased in Europe, amongst others through the voluntary initiative known as Vinyl 2010, in which the use of cadmium stabilisers in PVC was phased out in the EU-15 in 2001 and was completed by the end of 2007 following the enlargement of the phase-out in the EU-27 (EC, 2011).

Historically, lead has been used as pigment in plastics, although certain lead-based pigments were banned in Europe in 1989. The same applies to Mercury which has been used as a pigment and as a catalyst in the production in plastic.

Regulation and hazard information

Due to their intrinsic hazard properties, some metals are regulated in the EU.
For example, the Toy Safety Directive specifies migration limits for the 19 heavy metals (such as cadmium, lead, mercury, etc.) in toy parts accessible to children.
The REACH Regulation (1907/2006), impose restrictions. Entry 23 of Annex XVII limits the use of cadmium in plastic material, paint, and painted articles to a concentration of 0.01% (100 mg/kg) by weight, with an exemption for recycled PVC, allowing up to 0.1% (1000 mg/kg) by weight. Certain exemptions also permit the use of cadmium in articles colored with cadmium-containing mixtures for safety purposes. Furthermore, from November 2024, the use of lead in articles produced from PVC will be restricted to 0.1% by weight of the PVC material (entry 47 of Annex XVII). Restrictions on chromium (VI) mainly relate to its use in cement and leather articles (entry 47 of the Annex XVII). Entry 18 of Annex XVIII prohibits the use of mercury in preventing the fouling of microorganisms, preservation of wood, impregnation of heavy-duty industrial textiles, and treatment of industrial waters, while entry 18a prohibits its use in fever thermometers, and other measuring devices such as manometers, barometers, sphygmomanometers, thermometers other than fever thermometers. According to entry 27 of the Annex XVII, nickel is restricted in articles that come into contact with skin such as earrings, necklaces, bracelets, anklets, wrist-watch cases, watch straps, rivets, etc. with a release rate not exceeding 0.5 µg/cm^2/week. As of January 2022, Regulation (EU) 2017/852 prohibits the use of mercury as a catalyst in the production of vinyl chloride monomer. Mercury is also prohibited in plastic materials and articles intended to come into contact with food (Commission Regulation (EU) 2020/1245). Lastly, the RoHS Directive (2011/65/EU) restricts the use of several metals in electrical and electronic equipment, including cadmium (0.01% by weight), chromium (VI) (0.1% by weight), lead (0.1% by weight), and mercury (0.1% by weight).

Concentrations in articles and materials of recycled plastics

Studies which investigated presence of metals in consumer products made of recycled plastic could not be identified. However, there are few studies that measured metals in recycled plastic material.

For example, Eriksen et al. (2018) investigated presence of 15 metals in samples of recycled polymers (PET, PE, PP, and PS). Selected metals included Al, As, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Sb, Ti, and Zn. 10 samples of reprocessed plastic from household waste and 19 samples of reprocessed plastic from industrial waste, in the form of flakes or pellets, were collected from several recycling companies in Europe and China. According to the authors, reprocessed plastic from industrial waste consists of either pre-consumer waste from industry (such as off cuts) or waste from the industry that has been through a use phase (e.g. plastic wrapping around bales of straw used in the agricultural sector). LOD of the applied analytical

method was in the range of 0.04 mg/kg for Cd and As to 43 mg/kg for Al and detection frequency ranged from 10-85% for Fe and Ti, respectively.
The concentrations of detected metals ranged from the lowest, with As and Cd detected at 3 mg/kg in all plastic types, to the highest, with Ti measured at 12,800 mg/kg detected in reprocessed PP plastic from industrial waste. Concentrations of individual metals detected in different types of reprocessed plastic are given in TABLE 2-7.

Furthermore, Andersson et al. (2019) measured cadmium, lead and mercury in recycled plastic material collected from several recyclers across Europe. A total of 54 materials comprised of PS (n=17), PP (n=20), ABS (n=13), PE (n=1) and MEP (n=1) mainly coming from WEEE and ELV. The authors state that all materials were advertised as recycled material. Cadmium was detected in 13 samples. In the other 41 samples, cadmium was below the LOQ of 30 mg/kg. ABS and PE samples exhibited slightly higher cadmium levels, with the highest concentration of 109 mg/kg detected in an ABS sample. Lead was detected in 10 samples while in other 44 samples it was below the LOQ of 45 mg/kg. Total lead average value was 32 mg/kg with highest amount of 157 mg/kg detected in PP. All materials had mercury levels below the detection limit of 50 mg/kg.

The reviewed studies indicate that recycled plastic from both household and industrial waste can contain various concentrations of different metals, with levels varying widely depending on the source and type of recycled plastic. Since identified studies primarily focus on the presence of metals in recycled plastic rather than in the finished consumer goods, it is difficult to determine the relevancy for human exposure to these metals as it remains unclear whether the recycled plastic ultimately is used in the manufacture of new consumer articles.

TABLE 2-7. List of identified metals in recycled material.

Substance	Abbreviation	CAS No.	Product type	Material	Number of samples	Concentration interval, mg/kg	Sampling location (year)	Information source(s)
Aluminum	Al	7429-90-5	Reprocessed plastic from household waste	PET	2	284-451	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	195-808	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	207-390	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	537-885	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	12-913	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	284-443	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	360-436	Denmark	Eriksen et al 2018
Arsenic	As	7440-38-2	Reprocessed plastic from household waste	PET	2	3-3	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	3-39	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	6-15	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	3-3	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	3-18	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	3-32	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	3-4	Denmark	Eriksen et al 2018
Cadmium	Cd	7440-43-9	Reprocessed plastic from household waste	PET	2	3-3	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	24-450	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	159-581	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	3-3	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	3-164	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	3-3	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	3-3	Denmark	Eriksen et al 2018

Substance	Abbreviation	CAS No.	Product type	Material	Number of samples	Concentration interval, mg/kg	Sampling location (year)	Information source(s)
			Recycled plastic from WEEE and ELV	PS, PP, ABS, PE, MEP	54	<LOD-109	Europe	Andersson et al 2019
Cobalt	Co	7440-48-4	Reprocessed plastic from household waste	PET	2	313-1074	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	19-248	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	112-154	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	19-38	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	19-38	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	43-184	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	19-83	Denmark	Eriksen et al 2018
Chromium	Cr	7440-47-3	Reprocessed plastic from household waste	PET	2	48-239	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	179-483	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	143-737	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	48-48	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	48-183	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	48-91	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	48-66	Denmark	Eriksen et al 2018
Copper	Cu	7440-50-8	Reprocessed plastic from household waste	PET	2	75-107	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	159-581	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	101-217	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	65-75	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	65-489	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	96-220	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	65-193	Denmark	Eriksen et al 2018
Iron	Fe	7439-89-6	Reprocessed plastic from household waste	PET	2	175-569	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	110-735	Denmark	Eriksen et al 2018

Substance	Abbreviation	CAS No.	Product type	Material	Number of samples	Concentration interval, mg/kg	Sampling location (year)	Information source(s)
			Reprocessed plastic from household waste	PP	3	173-226	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	405-973	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	121-931	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	315-372	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	242-713	Denmark	Eriksen et al 2018
Mercury	Hg	7439-97-6	Reprocessed plastic from household waste	PET	2	117-117	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	117-161	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	117-164	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	117-138	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	117-146	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	117-145	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	117-138	Denmark	Eriksen et al 2018
Lithium	Li	7439-93-2	Reprocessed plastic from household waste	PET	2	18-21	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	20-36	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	28-129	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	14-16	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	14-45	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	14-17	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	23-132	Denmark	Eriksen et al 2018
Manganese	Mn	7439-96-5	Reprocessed plastic from household waste	PET	2	30-36	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	70-425	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	207-333	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	368-567	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	13-239	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	13-368	Denmark	Eriksen et al 2018

Substance	Abbreviation	CAS No.	Product type	Material	Number of samples	Concentration interval, mg/kg	Sampling location (year)	Information source(s)
			Reprocessed plastic from industrial waste	PS	3	13-36	Denmark	Eriksen et al 2018
Nickel	Ni	7440-02-0	Reprocessed plastic from household waste	PET	2	67-631	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	107-179	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	68-185	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	58-58	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	58-97	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	69-302	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	58-106	Denmark	Eriksen et al 2018
Lead	Pb	7439-92-1	Reprocessed plastic from household waste	PET	2	13-13	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	117-707	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	428-1840	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	15-17	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	13-104	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	13-40	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	13-33	Denmark	Eriksen et al 2018
			Recycled plastic from WEEE and ELV	PS, PP, ABS, PE, MEP	54	<LOD-157	Europe	Andersson et al 2019
Antimony	Sb	7440-36-0	Reprocessed plastic from household waste	PET	2	271-304	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	158-584	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	38-102	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	38-102	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	9-110	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	9-108	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	9-12	Denmark	Eriksen et al 2018
Titanium	Ti	7440-32-6	Reprocessed plastic from household waste	PET	2	643-339	Denmark	Eriksen et al 2018

Substance	Abbreviation	CAS No.	Product type	Material	Number of samples	Concentration interval, mg/kg	Sampling location (year)	Information source(s)
			Reprocessed plastic from household waste	PE	5	133-363	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	1740-3660	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	192-1620	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	112-1030	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	358-12800	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	257-3500	Denmark	Eriksen et al 2018
Zinc	Zn	7440-66-6	Reprocessed plastic from household waste	PET	2	660-660	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PE	5	150-979	Denmark	Eriksen et al 2018
			Reprocessed plastic from household waste	PP	3	122-345	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PET	2	660-660	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PE	11	101-823	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PP	3	660-697	Denmark	Eriksen et al 2018
			Reprocessed plastic from industrial waste	PS	3	552-824	Denmark	Eriksen et al 2018

2.3.3.5 PAH (Polyaromatic hydrocarbons)

Source of presence and function in plastics

Polycyclic aromatic hydrocarbons (PAH) are usually present as complex mixtures of substances of several hundred congeners. PAH in plastics is thought to originate from contamination of the black pigment used for colouring plastics (carbon black), as impurity in plasticisers from mineral oil and coal-based extender oils (in rubber) and/or from thermal processing of plastics (Hansen et al., 2014; Kastbjerg et al., 2021).

Regulation and hazard information

According to the CLP Regulation (1272/2008), PAH are recognised as carcinogens. The substances benzo[a]pyrene (BaP, CAS no. 50-32-8), benz[a]anthracene (CAS no. 56-55-3), benz[e]acephenanthrylene (CAS no. 205-99-2), benzo[j]fluoranthene (CAS no. 205-82-3) and benzo[k]fluoranthene are all classified as Carc. 1B. Furthermore, some PAH are toxic to the aquatic environment, and some are considered skin sensitising (CLP Regulation (1272/2008)). The use of PAH is restricted in several appliances according to Annex XVII in REACH (1907/2006), entry 50. Thus, the eight listed PAH are not allowed in articles for the general public in concentrations above 1 mg/kg (0.0001 % by weight) and above 0.5 mg/kg (0.00005 % by weight) in toys and childcare articles. Furthermore, PAH are restricted in extender oils used for the production of tyres or parts of tyres (concentration limit 1 mg/kg (0.0001 % by weight) for BaP and 10 mg/kg (0.0010 % by weight) for all listed PAH). Danish national legislation also restricts PAH in toys, as the Executive Order on Toys ((BEK no. 815 of 07/06/2022)) prohibits CMR substances in accessible parts of toys, unless if the concentration of the CMR substance is below the classification limit.

Concentrations in articles and materials of recycled plastics

Dahl et al. (2024) detected no PAH in an analysis of household-collected HDPE and PET from Denmark, Europe, and India. Kastbjerg et al. (2021), on the other hand, report concentrations of PAH migrating from recycled plastic packaging to cosmetic product simulant (isooctane). Phenanthrene (CAS no. 85-01-8) was the most abundantly detected substance, being present above LOD in six out of seven samples in concentrations up to 6.2 mg/kg simulant. Pyrene (CAS no. 129-00-0) and fluoranthene (CAS no. 206-44-0) were detected in four out of seven samples in concentrations up to 0.88 and 1.6 mg/kg simulant, respectively. Naphthalene (CAS no. 91-20-3) and fluorene (CAS no. 86-73-7) were detected in two out of seven samples in concentrations up to 4.4 and 0.83 mg/kg simulant, respectively. Lastly, acenaphtene (CAS no. 83-32-9) and anthracene (CAS no. 120-12-7) were detected in two out of seven samples in concentrations up to 0.52 and 1.7 mg/kg simulant, respectively.

It should be noted that the reported concentrations are based on the amount migrated into the cosmetic product, hence they do not directly reflect the concentrations of the substances in the recycled plastic packaging and cannot be compared to the concentration limits defined under REACH. Neither the colour of the plastic packaging (black or dark colours indicating the potential presence of carbon black pigments), nor any other information regarding the possible origin of PAH in the recycled plastic was provided.

Moreover, ECHA (2023a) mention that articles made of recycled rubber (e.g., tyres) may contain PAH.

2.3.3.6 Primary aromatic amines (PAA)

Source of presence and function in plastics

Primary aromatic amines (PAA) are a group of substances consisting of an aromatic ring attached to a primary amine group. PAA are not intentionally added to plastics; however, they are found in fractions of recycled plastics, including food contact materials (Kastbjerg et al., 2021; Dahl et al., 2024). Dahl et al. (2024) reports the source of PAA to be the degradation of organic colourants (azodyes) during the recycling process. This information is supported by analytical findings of PAA occurring at higher concentrations in samples of grey pellets than in samples of white pellets (Dahl et al., 2024).

Hansen et al. (2014) recognises that it is often difficult to identify the source of aromatic amines in plastics, e.g., PAA in polyamide may originate from hydrolysis of aromatic diisocyanate, PAA used as stabilisers or from a black colorant.

Substances include o-ansidine (CAS no. 90-04-0), o-toluidine (CAS no. 95-53-4), 3,3-dichlorobenzidine (CAS no. 91-94-1), 4,4-diaminophenylmethane (CAS no. 101-77-9), and p-cresidine (CAS no. 120-71-8) (Dahl et al., 2024; Appendix 8 in REACH regulation)[10].

Regulation and hazard information

Due to their carcinogenic, mutagenic and/or reprotoxic properties, azo colourants and azodyes, which release PAA, listed in Appendix 8 to REACH annex XVII (22 substances), or contained in Appendix 9[11] to REACH annex XVII, are restricted under REACH in textile and leather articles (REACH Annex XVII, entry 43). The concentration limit for azodyes is 1000 mg/kg (0.1 % by weight). Azodyes, which by reductive cleavage of one or more azo groups, release one or more of the PAA in detectable concentrations, i.e., above 30 mg/kg (0.003 % by weight) in articles shall not be used, in textile and leather articles with direct skin contact (REACH Annex XVII, entry 43).

Concentrations in articles and materials of recycled plastics

Dahl et al. (2024) and Kastbjerg et al. (2021) measured the migration of PAA to a cosmetic product simulant (3% acetic acid) from HDPE and PET waste collected from households in Denmark, Europe, and non-EU countries (including India, Indonesia, and Egypt). Whereas no PAA were detected in the PET samples (Dahl et al., 2024), the HDPE samples contained various PAA.

The HDPE samples collected in Denmark contained o-toluidine (migration up to app. 0.45 mg/kg simulant), o-anisidine (up to app. 0.65 mg/kg simulant), 3,3-dichlorobenzidine (up to app. 0.1 mg/kg simulant), as well as low levels of 4-chloro-o-toluidine, 2,4-diaminotoluene, 4,4-diaminodiphenylmethane and p-chloroaniline (concentrations less than 0.05 mg/kg simulant).

HDPE samples collected in Europe contained 3,3-dichlorobenzidine (up to app. 0.22 mg/kg simulant), 4,4-diaminodiphenylmethane (up to app. 0.28 mg/kg simulant), p-cresidine (up to app. 0.31 mg/kg simulant) as well as concentrations of o-toluidine and o-ansidine below 0.05 mg/kg simulant.

HDPE samples collected outside of Europe contained 4,4-diaminodiphenylmethane (up to app. 0.62 mg/kg simulant) and p-cresidine (up to 0.2 mg/kg simulant) as well as o-toluidine, o-ansidine, 3,3-dichlorobenzidine and 4-chloro-o-toluidine at levels lower than 0.05 mg/kg simulant.

The database is too small to allow any general conclusions on concentration levels in waste samples from different countries or which PAA may be present in which polymers. It should be noted that the reported concentrations are based on the amount migrated into the cosmetic product, hence they do not directly reflect the concentrations of the substances in the recycled plastic packaging and cannot be compared to the concentration limits defined under REACH.

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[10] Appendix 8, Entry 43 — Azocolourants — List of aromatic amines, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02006R1907-20231201#tocId1216.

[11] Appendix 9, Entry 43 — Azocolourants — List of azodyes, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02006R1907-20231201#tocId1218.

Any information regarding the possible origin of the PAA in the recycled plastic was not provided.

2.3.3.7 Benzotriazole UV stabilizers (BUVs)

Source of presence and function in plastics

Benzotriazole UV stabilizers (BUVs) are widely used substances added to plastics to prevent degradation from sunlight exposure (Brosché et al., 2021; Potrykus et al 2024).

Regulation and hazard information

In January 2024, ECHA published a screening report to assess whether the use of four benzotriazoles in articles, UV-328 (CAS no. 25973-55-1), UV-327 (CAS no. 3864-99-1), UV-350 (CAS no. 36437-37-3) and UV-320 (CAS no. 3846-71-7) should be restricted under REACH (ECHA, 2024). All four substances are recognized very persistent and very bioaccumulative (vPvB) substances (UV-328 and UV-320 are additionally recognised PBT substances) and the substances have been included in Annex XIV of REACH ("Authorisation List"). ECHA considers that uses of the substances in articles may pose a risk to the environment which is not adequately controlled.

UV-328 is already listed on Annex A (Elimination) under the Stockholm Convention[12], and its restriction for use in articles is expected to be implemented through the POP regulation.
For UV-320, UV-327 and UV-350, ECHA's view is that the requirements to prepare an Annex XV dossier for restriction (on all or selected) uses of these substances in articles are met.

For five additional BUVs (UV-329, CAS no. 3147-75-9; UV-234, CAS no. 70321-86-7; UV-928, CAS no. 73936-91-1; UV-P, CAS no. 2440-22-4 and UV-326, CAS no. 3896-11-5) needs for regulatory action at EU level have been concluded. While the identification as SHVC is realized, harmonized classification is still pending (ECHA, 2022).

Concentrations in articles and materials of recycled plastics

In the IPEN report by Brosché et al. (2021) the authors cite several studies documenting the migration of BUVs from plastics e.g., used as food contact materials.

Sakuragi et al. (2021) measured the concentrations of nine representative BUVs in virgin plastic products: plastic bottle caps of 10 beverages, in four food packages, and in four plastic shopping bags purchased from Japanese grocery stores. Upon GC–MS analysis, eight BUVs were detected in the samples (all except UV-320). Notably, UV-P and UV-326 were detected in all the bottle caps at concentrations in the order of ng/g.

Brosché et al. (2021) purchased 24 samples of recycled HDPE plastic pellets from local recycling industries in 23 countries in South America, Africa, and Asia. The pellets were analyzed for presence of the following BUVs: UV-234, UV-326, UV-327, UV-328, UV-329, and UV-P. All pellet samples contained the UV stabilizer UV-326 (range 0.26×10^{-3} – 83.2 mg/kg), and 19 out of the 24 analysed samples contained UV-327 (range 0.07×10^{-3} – 56.2 mg/kg). UV-234, UV-328, UV-329 and UV-P were also detected, but in fewer samples (13-17) and in concentrations below 9.6 mg/kg (Brosché et al., 2021).

Even though the above results are from Japan/outside Europe, they are considered relevant here, as food packaging and bottles are often recycled (see section 2.3.3) and because recycled PET and HPDE may be sourced from countries outside the EU, see section 2.3.1.7).

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[12] https://www.pops.int/TheConvention/ThePOPs/TheNewPOPs/tabid/2511/Default.aspx

No data has been identified to what extent BUVs are present in recycled consumer products on the European market. However, the authors highlight that such recycled plastic may also end up in consumer products such as kitchen utensils and toys (Brosché et al., 2021).

2.3.3.8 Benzophenone UV stabilisers

Source of presence and function in plastics

Benzophenones are used as UV stabilisers in plastics (Song et al., 2021) and occur in both virgin and recycled plastics (Dahl et al., 2024). The most common UV stabilisers in plastic are benzophenone (CAS No. 119-61-9) and 4-phenylbenzophenone (CAS no. 2128-93-0) (Dahl et al., 2024).

Regulation and hazard information

Benzophenone (CAS no. 119-61-9) is classified as carcinogenic 1B according to the CLP Regulation (1272/2008). Related substances, for example 4-phenylbenzophenone (CAS no. 2128-93-0) and 2-methylbezophenone (CAS no. 131-58-8), have no harmonized classifications. Benzophenone has been evaluated under CoRAP by the Danish EPA, which initiated the harmonized classification of the substance. Other regulatory actions (SVHC identification, restriction or other risk management measures) were not considered in the substance evaluation conclusion document.[13]

Concentrations in articles and materials of recycled plastic

Dahl et al. (2024) and Kastbjerg et al. (2021) measured the migration to a cosmetic product simulant (95% ethanol) of several UV photo initiators (including benzophenone) from HDPE and PET waste collected from households in Denmark, Europe, and non-EU countries (including India, Indonesia, and Egypt). No UV photo initiators were detected in the PET samples (Dahl et al., 2024); however, the HDPE samples contained various UV photo initiators, the most abundant substances being benzophenone and 4-phenyl benzophenone.

The HDPE samples collected in Denmark contained up to app. 1.2 mg benzophenone/kg simulant and up to app. 2.8 mg 4-phenylbenzophenone/kg simulant.
The measured concentrations of benzophenone and 4-phenylbenzophenone in HDPE samples collected in Europe were up to app. 7.9 mg/kg simulant and 1.2 mg/kg simulant, respectively.
For HDPE samples collected outside Europe, concentrations of benzophenone of up to app. 2.2 mg/kg simulant were reported, while the concentration of 4-phenylbenzophenone was up to app. 0.5 mg/kg simulant.

Concentrations of other substances belonging to the group of benzophenones, hereunder methyl-2-benzoylbenzoate (MBB; CAS no. 606-28-0), 2-isopropylthioxanthone (2-ITX; CAS no. 5495-84-1), 4-dimethylaminobenzoic acid ethyl ester (CAS no. 10287-53-3), 2-ethylhexyl 4-(dimethylamino)benzoate (CAS no. 21245-02-3) and 2,4-diethyl-9H-thioxanthen-9-one were also measured. All of the before-mentioned substances were detected at concentrations lower than 0.5 mg/kg simulant in all samples (Dahl et al., 2024; Kastbjerg et al., 2021).

Antvorskov et al. (2023) also reports additional concentrations of benzophenones in PCR plastics based on migration to cosmetic products: Benzophenone was found at a concentration of 2.2 mg/kg simulant, while 2.8 mg/kg simulant of 4-phenyl benzophenone (CAS no. 2128-93-0) and 0.6 mg/kg simulant of 2-methylbenzophenone was found.

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[13] Substance Evaluation - CoRAP list, benzophenone: https://echa.europa.eu/da/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table/-/dislist/details/0b0236e1807e5a83

It should be noted that the concentrations are based on migration, hence they do not directly reflect the concentrations of the substances in the recycled plastic.

2.3.3.9 Alkylated phenols and their degradation products

Source of presence and function in plastics

Alkylated phenols are added to plastics as stabilisers and antioxidants. With time and usage, these substances and their degradation products may migrate out of the plastic (Kastbjerg et al., 2021). The group covers a range of substances, including tris-(2,4-di-t-butylphenol) phoshite (CAS no. 31570-04-4), 2,6-bis(1,1-dimethyl)-4-methylphenol (BHT; CAS no. 128-37-0) and tert-butyl-4-methoxyphenol (BHA; CAS no. 25013-16-5) as well as degradation products such as 2,4-di-tert-butylphenol (CAS no. 96-76-4) (Kastbjerg et al., 2021; Antvorskov et al., 2023).

Regulation and hazard information

Tris-(2,4-di-t-butylphenol) phoshite is under assessment as persistent, bioaccumulative and toxic (PBT), but has no other classifications in the CLP Regulation (1272/2008). 2,4-di-tert-butylphenol and BHT are both under assessment as endocrine disrupting and classified as very toxic to aquatic life according to the CLP Regulation (1272/2008). According to the CLP Regulation (1272/2008), BHA is classified as being toxic to aquatic life, harmful if swallowed, causes serious eye damage and skin irritation, may cause respiratory irritation, is suspected of causing cancer and suspected of damaging fertility. Some alkylated phenols and their degradation products have been identified as damaging liver and kidney and causing genetic damage (Kastbjerg et al., 2021).

Concentrations in articles and materials of recycled plastic

Kastbjerg et al. (2021) analysed concentrations of alkylated phenols and their degradation products migrating from samples of PCR plastics to a cosmetic product simulant consisting of 95% ethanol over a period of three days. The degradation product 2,4-di-tert-butylphenol was detected in six out of seven samples, concentrations ranging from below LOD to 6.5 mg/kg simulant. BHT was also detected in six out of seven samples, concentrations ranging from below LOD to 5.9 mg/kg simulant.

Antvorskov et al. (2023) also measured the concentration of alkylated phenols in PCR plastics based on migration to cosmetic products: the degradation product 2,4-di-tert-butylphenol was found at a concentration of 160 mg/kg simulant, while tris-(2,4-di-t-butylphenol) phosphite was found at a concentration of 1000 mg/kg simulant.

It should be noted that the concentrations from both above-mentioned studies are based on migration, hence they do not directly reflect the concentrations of the substances in the plastic products. However, the results show that the mentioned stabilisers are present in the recycled plastic.

2.3.3.10 Bisphenols

Source of presence and function in plastics

Bisphenols belong to the chemical group of phenols, which are used in plastics due to their antioxidant properties. In PE and PP, a concentration of 0.05 to 0.2% phenols is typically added to the plastic, while higher concentrations (up to 2%) may be added to ABS, PS, and synthetic rubber (Poulsen et al., 2020). Additionally, bisphenol A may also be present as a residual monomer in epoxy resins such as bisphenol A diglyceride ether (BADGE) (Hahladakis et al., 2018).

Regulation and hazard information

A well-known substance in the bisphenol group is Bisphenol A (BPA; CAS no. 80-05-7) which is widely used in plastics globally (IPEN, 2020). BPA has been restricted in thermal paper in the EU when it was listed in Annex XVII, entry 66, under REACH (1907/2008) in 2016. Furthermore, BPA is identified as a SVHC due to its reprotoxic and endocrine disrupting properties for human health and environment. According to the harmonised classification under the CLP Regulation (1272/2008), BPA is toxic to reproduction, skin sensitizing, endocrine disrupting, toxic to aquatic life, causes eye damage and may cause allergic skin reaction and respiratory irritation. Additionally, Toy Safety Directive (Directive 2009/48/EC) specifies migration limit value of 0.04 mg/l for bisphenol A in toys intended for used by children under 3 years or in other toys to be placed in the mouth. The limit value is implemented into Danish law via the Executive Order on toys (BEK no. 815 of 07/06/2022).

Other bisphenol analogues include bisphenol AF (BPAF; CAS no. 1478-61-1), bisphenol F (BPF; CAS no. 2467-02-9) and bisphenol S (BPS; CAS no. 80-09-1). Like, for BPA, the classification of BPS under the CLP Regulation (1272/2008) is harmonised, stating that BPS is toxic to reproduction, endocrine disrupting, toxic to aquatic life, eye damaging and skin sensitizing. According to the CLP Regulation (1272/2008), BPF is classified (not harmonised) to be toxic to aquatic life, cause eye damage and skin irritation and to possibly cause respiratory irritation and allergic skin reaction. It is important to note that there are some ongoing discussions regarding changes in the classifications for BPF. BPAF similarly may damage fertility, is toxic to aquatic life, causes eye damage and may cause damage to organs through prolonged or repeated exposure (not harmonised classification under the CLP Regulation (1272/2008)).

Concentrations in articles and materials of recycled plastic

IPEN (2020) and Hahladakis et al. (2018) report that BPA may occur in recycled plastic, however, no concentrations are available. Hahladakis et al. (2018) report migration of BPA into food products from virgin food contact materials (e.g., cans lined with plastic resins, PC bottles, PE and PP plastic bags and film). These findings are considered of limited relevance here and figures of migration are therefore not reported.

2.3.3.11 Residual monomers

Source of presence and function in plastics

Residual monomers occur in plastic polymers due to uncomplete reactions in the polymerization process, where not all monomers (the "building blocks" of plastic polymers) are completely reacted. The residual monomers generally occur in low concentrations, typically between 0 and 2% (Poulsen et al., 2019).

Regulation and hazard information

In the EU Expert Group on Toy Safety ”Sub-group Chemicals”[14], the following monomers have been identified as particularly problematic, based on carcinogenic properties and their use in polymers used for toys:

- Vinyl chloride (also chloroethene, CAS no. 75-01-4, present in PVC).
- 1,3-Butadiene (CAS no. 75-01-4, present in ABS, styrene-butadiene rubber (SBR/SBS), and acrylo-nitrile-butadiene rubber (NBR)
- Acrylonitrile (CAS no. 107-13-1, present in ABS, NBR, styrene-acrylonitrile (SAN), acrylonitrile-styrene-acrylate (ASA), and NBR)
- Acrylamide (CAS no. 79-06-1, present in polyacrylamide (PAM))
- Styrene (CAS no. 75-01-4, present in PS, ABS, SBR, SAN, styrene-ethylene-buthylene-styrene rubber (SEBS), styrene butadiene block co-polymer (SBC), and unsaturated polyesters)

[14] ANEC Position Paper https://anec.eu/images/ANEC-CHILD-2018-G-065.pdf

For vinyl chloride and acrylamide, restrictions are defined under REACH (entry 2 and entry 60, respectively). However, those have limited or no relevancy for consumer articles. More specifically, restriction on vinyl chloride does not apply to articles, as it only concerns propellants in aerosols. The restriction of acrylamide might be of relevance as it restricts acrylamide in mixtures including plastic granules and pellets.

The listed five monomers were investigated in detail in a report by the Danish EPA regarding their presence and migration from plastic materials used in toys (Poulsen et al., 2019). Additionally, 15 other monomers with CMR properties that can be present in toys are listed, but not assessed further in the report by Poulsen et al. (2019)[15].

Concentrations in articles and materials of recycled plastic
Poulsen et al. (2019) analysed content and migration of these monomers in 29 samples of toys made of virgin plastic (ABS, PS, PVC, and SEBS rubber) as well as in a few samples of PIR plastic.

The analysis of the residual monomers in the virgin toys showed that concentrations were either below the detection limit or detected at low levels, with the exception of the ABS toys (average residue of 26.7 mg/kg for acrylonitrile, 0.57 mg/kg for butadiene, and 842 mg/kg for styrene) and styrene concentration in PS toy (351 mg/kg). Migration analyses conducted on certain toys indicated no migration above the detection limit.

In addition to the articles made of virgin plastic, PIR samples of both ABS and PS were provided from two different Danish recycling companies. The ABS material is presumably stemming from a toy producer, while the PS sample was originated from food contact material.

Both PIR pellet samples and PIR plastic in the form of plates (pellets moulded to plates) were analysed. The plates have thus undergone all the manufacturing processes which toys produced from recycled plastic undergo, making them representative of toy articles made from recycled plastic.

The content of the residual monomers acrylonitrile, butadiene and styrene in the pellets of recycled ABS were 10, 2.1 and 330 mg/kg, respectively. The content of styrene in the PS granules was 270 mg/kg. The remaining monomers were not detected in the samples. Content analyses were not performed on the plastic plates; therefore, it is not possible to assess whether the additional process step may have reduced the content of the (rather volatile) monomers.

Additionally, migration to ethanol and stomach acid simulant was tested. None of the monomers were found to migrate at concentrations above the LOD from any of PIR plastic samples (LOD in ABS samples 0.04 – 3.6 mg/kg, LOD in PS samples 0.15 – 3.9 mg/kg).

Poulsen et al. (2019) compared the analytical results of residual monomers in virgin plastic toy articles and the PIR plastic and did not find a difference with regard to content and migration of the relevant monomers. However, it is noted that only few samples (10 ABS and five PS toys compared to two samples of each PIR-ABS and PIR-PS) were included. Furthermore, the authors note that large variations in content (and migration) of the relevant residual monomers in recycled material are expected, depending on the origin of the recycled material.

[15] These comprise bisphenol A, phenol, formaldehyde, ethylene oxide, propylene oxide, 2-methyl-1,3-butadiene, epichlorhydrine, ethylenimine, 2,4-toluene-diisocyanate, 2,4′-methylene-diphenyl diisocyanate, hydroquinone, vinyl acetate, vinylidene chloride, 1,3-phenylenediamine, 1,3,5-trioxane

Based on their findings, Poulsen et al. (2019) conclude that the presence of the any of the monomers does not constitute a risk for any of the examined toy materials (ABS, PS, PVC, SEBS and SBC) due to the low migration of the monomers from the plastic materials.

Additional references on residual monomers in recycled plastic have not been identified.

2.4 Discussion and conclusion on recycled plastic in consumer products

During phase 1, a literature review, a stakeholder consultation, and a product survey was carried out. These activities aimed to provide answers to the main objectives of this project phase as described in section 2.1. The following sections summarise the findings.

2.4.1 Types of plastic polymer used in consumer articles made of recycled plastic

During the consumer article survey (section 2.3.2), 62 products were identified on Danish and European websites. Information on the polymer type were often not provided in the article descriptions on the retailers' websites. For around 31% of the products in the survey, the polymer type was unknown. For the products for which the polymer was stated, PET (including polyester) was the most abundantly used polymer (41%) in the recycled consumer articles in focus (toys, childcare articles, textiles for clothing as well as home textiles, and furniture).

Supply chain actors (collectors, recyclers and/or compounders) of recycled plastics interviewed during the stakeholder consultation report that the primarily recycled polymers are PE, PP, PS, ABS, PET, nylon and – to a lesser degree – PVC. Some recyclers/compounders do only process certain polymers. All these polymers are used in consumer products. However, no articles, which are relevant for the scope of this project, made of PVC and ABS were identified, which fall within the focus area of consumer products in this study, i.e. toys, children's products (e.g. child seats, car seats, strollers), children's clothing, as well as furniture, home textiles and interiors (see section 2.1). According to manufacturers, the polymers PP, PE and PET are the most commonly used polymers for the manufacture of consumer products from recycled plastic.

According to indications obtained during the stakeholder consultation and information from the literature review, PET is more widely used for manufacture of recycled consumer products, because the traceability of PET fractions is higher than for other polymers, e.g., PP and PE, especially when collected post-consumer. PET is typically collected separately and is therefore more uniform and less contaminated than other polymer fractions, allowing the recycled polymer to be used for a wider range of applications.

2.4.2 Origin of the recycled plastic used for consumer products

Information on whether the recycled plastic in consumer articles stems from post-industrial or post-consumer waste, is often not provided in the article descriptions by the manufacturers or retailers; in the consumer article survey (section 2.3.2), the origin of the recycled plastic was unknown for about half of the products, whereas app. 40% of the products were made from PCR plastic and 10% were made from PIR. It is noted that there is some uncertainty related to these figures, as they are based on a relatively small number of consumer articles (62 articles) and article descriptions on the retailers' websites.

According to communication with stakeholders, both post-industrial and post-consumer plastic are recycled, however, PIR plastic is easier to recycle due to its high purity and known composition. PIR plastic can be received from the hygiene, food production, building or pipe industry, while PCR plastic may originate from household waste, recycling stations, and manufacturers who have a take-back agreement with their customers.

A Danish compounder stated in the stakeholder consultation that 30-40% of their produced volume is PIR but they also state that the fraction of PCR is increasing due to increased focus on resources and sustainability. A Danish recycler, reports that 95% of their production is based on PCR plastics (primarily from packaging) and 5 % from PIR, while another European recycler relies entirely on PCR.

It has not been possible to develop a complete overview of the PCR and PIR plastic used for consumer articles on the Danish or European market within the scope of this project. Overall, the data from the consumer article survey and the stakeholder consultation indicate that PCR plastic is more commonly used than PIR plastic in consumer products with an expected increase of the volumes of PCR plastic. However, it should be noted, that there is uncertainty related to the information about the origin of the recycled plastic from the consumer article survey, because the data stems from retailers, who have an interest in promoting their products by claiming that they are made from PCR plastic.

2.4.3 Additives and their degradation products occurring in consumer articles made of recycled plastics

There are several reason why hazardous substances can be present in consumer products made from recycled plastic. One reason is the presence of additives that were originally in the virgin plastic products. These additives, added for functional purposes such as durability, flexibility, colour, or present as impurities, remain in the recycled material. Another reason is the presence of legacy additives, which originate from the recycled plastic and were not intentionally added to the new recycled products. Additionally, the recycling process may involve the introduction of functional additives to enable the effective use of recycled plastic fractions such as heat stabilizers, odour maskers and/or pigments. The resulting content of potentially hazardous substances has been investigated in the literature review.

Despite regulations in place limiting the reuse of plastic containing brominated flame retardants, obtained results showed that brominated flame retardants (including octaBDE, decaBDE, HBCD, other PBDEs, and some nBFRs) are frequently detected in various consumer products such as children’s toys, kitchen utensils and hair accessories. The authors of these studies conclude that the origin of detected BFRs is likely from recycled plastic due to concentrations, which are below the levels at which a flame retardancy functionality would be provided. Additionally, those product groups do not require flame retardance. The case is similar for OPFRs and some phthalates in children’s toys, where the substances were detected in concentrations too low to alter the material properties, thus indicating their presence likely stems from the use of recycled materials or cross-contamination processes.

There are some indications that several PAH, PAA, benzophenone UV stabilizers and alkylated phenols are present in recycled plastic packaging, however, this was based on migrated concentrations into cosmetic product simulants and the exact concentration of detected substances in recycled plastic packaging is not known.
PAAs are not intentionally added to plastics but commonly found in fractions of recycled plastics, especially in coloured plastic fractions, as degradation products of azo colourants. Alkylated phenols are added to plastics as stabilisers and antioxidants and both the substances as well as their degradation products have been detected in recycled plastic packaging.

Several benzotriazole UV stabilizers were detected in consumer products purchased in Japan. However, since recycled PET and HDPE may be sourced from countries outside the EU, exposure to consumer articles made of recycled PET and HDPE containing these substances may also occur within EU.

The presence and migration of carcinogenic residual monomers (vinyl chloride, 1,3-butadiene, acrylonitrile, acrylamide, and styrene) from plastic materials used in toys were also investigated. It was concluded that, due to the low migration levels of the monomers from the virgin and PIR plastic materials, there was no risk associated with the presence of monomers in any of the examined toy materials (ABS, PS, PVC, SEBS, and SBC). Data on presence and migration of residual monomers from PCR plastic has not been available. On the one hand, the presence of monomers, yielded from the degradation of the plastic polymers in food contact materials, has been reported. On the other hand, the removal of the volatile residual monomers can also be expected in the recycling and re-compounding process steps that involve elevated temperatures. No information has been identified on whether the degradation of polymers (yielding carcinogenic residual monomers) occurs at an enhanced rate in PCR plastic compared to virgin and PIR plastic. Therefore, it cannot be concluded on whether PIR and PCR plastic differ in the content of residual monomers.

During re-compounding, processes (moulding and extrusion) at elevated temperatures, evaporation may contribute to the release of some semi-volatile and volatile substances in the recycled material, e.g., VOC as residual monomers or phthalates. However, another study on different recycled plastic fractions in Denmark also suggested that phthalates are not removed during recycling and may persist and accumulate in recycled plastics.

In conclusion, the literature review showed that numerous substances with hazardous properties can be present in consumer articles or recycled plastic material potentially used for consumer articles. Many of these substances appear as legacy additives, which use in consumer articles is regulated and/or restricted via the REACH Regulation, POP Regulation, RoHS Directive and/or the Toys Directive, e.g., brominated flame retardants as PBDE, some phthalates, metals, eight PAH as well as some azodyes and the aromatic amine resulting from them. Other substances are only partly or not regulated in consumer articles via European law, e.g., novel flame retardants (such as TBBPA and its derivatives, brominated diphenyl ethyls and brominated phthalates), non-halogenated organophosphorus flame retardants, benzotriazole UV-stabilisers (except UV-328) and benzophenone-related UV-stabilisers.

2.4.4 Traceability and information transfer through the supply chain

Information on traceability and information transfer through the life cycle and supply chain of recycled plastic has been described based on the results of the stakeholder consultation, the literature review and the project team's professional experience.

The supply chain of recycled plastic articles on the Danish/European market involves numerous actors, who may be located both within and outside of Europe. The source and type of the recycled plastic is not always known in all parts of the supply chain.

For production of virgin plastics pellets, the producer may add certain additives in order to obtain the required properties, e.g., plasticisers, colourants, flame retardants, stabilisers. The downstream user, who buys such pellets, may be entitled to a safety data sheet (SDS) according to Article 31 of REACH (1907/2006). However, as soon as the polymer has been formed into a specific shape, surface, or design, which is defining for the use of the product, it is classified as an article and not a substance, and the SDS and other obligations for substances and mixtures are no longer applicable. However, for articles the supplier has the obligation to communicate the presence of substances of very high concern (SVHC) above 0.1 % by weight to the customer (Article 33 of REACH).

During the manufacturing phase of virgin plastic articles, a fraction of the plastic is usually generated as waste. This fraction either contains no or a known quantity of additives and is of high quality and may therefore be sold to recyclers and re-compounded into recycled plastic pellets. For such fractions, an SDS may be provided to the recycler. The resulting material is referred to as post-industrially recycled (PIR) plastics. A SDS is only required, if the PIR mixture is classified as hazardous or if it contains any (known) hazardous substances. The PIR mixture may, however, still contain hazardous substances (either below classification limits or unknown). Also, the requirement is due to European law (REACH) which non-EU actors are not obliged to comply with.

The end-user of an article usually does not know which hazardous substances are present in the articles. As such, when post-consumer waste arrives at the recycler it is typically not known which hazardous substances are present, as this information is lost during the use phase. The SCIP database, setting requirements to companies to submit information about SVHC in articles to ECHA, aims at closing this knowledge gap. However, no useful information regarding consumer articles made of recycled plastic could be extracted from the database at this point of time[16].

Knowledge about presence of chemicals in the plastic waste is generated during the recycling, re-compounding and manufacturing of recycled plastic articles steps. According to Article 6.1 of the Waste Framework Directive (2008/98/EC), the analysis shall be performed by the actor who is obliged to ensure the end-of-waste criteria.

Based on information from recyclers, the methods and frequency of chemical analyses of the recycled batches are highly varying and depend on the recycled waste stream, the recycler's practice, and the customers' requirements. Based on the experience of the operator and the input waste, it can be estimated whether an output has a high chance of containing hazardous substances thus requiring analysis.

No standards exist for how often a batch of recycled plastic must be analysed for its content of hazardous chemicals, nor which chemicals should be investigated. Batch-specific declarations on, e.g., the content of metals, content of SVHC substances or CLP compliance, may be provided by recyclers or compounders on demand from manufacturers.

For the recycled plastic pellets, a SDS is created and provided to the manufacturer of plastic articles. The SDS informs the manufacturers that the plastic is made from recycled waste and must also include added hazardous additives and leftover hazardous substances from the first use if present above a certain concentration threshold.

[16] SCIP Database, available at https://echa.europa.eu/scip-database?p_p_id=diss_scip_portlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&_diss_scip_portlet_javax.portlet.action=searchArticlesAction. Search for consumer articles including the term "recycled".

3. Selection of focus area, purchase of products and chemical analyses

3.1 Selection of focus area

Through the activities carried out during phase 1 of this project, several topics with relevancy regarding consumer safety related to the use of articles made from recycled plastic have been identified. These potential focus areas are presented in TABLE 3-1 along with argumentation of their relevancy.

TABLE 3-1. Potential focus areas for further investigation of chemical content in phase 2.

Potential focus area	Relevancy
(i) Plastic type focus	
Articles of PET	Generally, concentrations of hazardous substances appear to be low, but contaminations with some metals and benzotriazoles have been shown in recycled and virgin PET from non-EU. As the recycled PET may be sourced from outside of the EU, such contaminations may also occur in consumer articles on the European market. Additionally, PET appears to be the most commonly PCR polymer.
Articles of PS and/or ABS	Many impurities suspected (Pivnenko et al., 2017). Styrene is found in PS, and acrylonitrile, butadiene, and styrene in ABS (Poulsen et al., 2019). DEHP identified in recycled PS from WEEE/ELV (Andersson et al., 2019). Recycled ABS from WEEE/ELV showed increased levels of cadmium (Andersson et al., 2019). Also, the product survey identified PS articles originating from outside of the EU (e.g., India), making it more likely that the source materials are not compliant with EU chemical regulation.
Articles of black plastic (not advertised as recycled)	Strakova et al. (2018) and Brosché et al. (2021) report that black plastic articles (or black parts of plastic articles) may originate from recycled electronic waste, and hence contain hazardous substances, e.g., BFRs.
Articles made of recycled WEEE and ELV	Recycled consumer articles containing recycled WEEE and/or ELV material have been identified during the literature review (Strakova et al., 2018). However, to be compliant, consumer products should not contain recycled WEEE and/or ELV material if concentrations of restricted substances are above the limits set by existing legislation. Hence, this focus area is deemed of less relevance.
(ii) Product category focus	
Outdoor furniture	PCR plastic is often used for outdoor appliances, due to its potentially mixed composition of polymers and unknown contents of additives (stakeholder information). Addition of certain potentially hazardous substances (e.g., UV-stabilisers, antioxidants) may be required for such articles to last in the outdoor environments. Also, such articles are usually not regulated as childcare articles, but children's exposure can be expected. However, children's exposure duration is limited. Additionally, items from these product group are often costly, allowing only for a small number of products for analysis within the project budget.

Potential focus area	Relevancy
Textile articles	Several retailers brand their textile products as made from recycled plastic, often plastic bottles (PCR plastic). The most commonly use recycled plastic type for textiles is PET (polyester), therefore the same argumentations as for articles made of PET applies. Substances in textile apparel are not regulated under a specific regulation, but some substances are specifically restricted under REACH regarding their use in textiles with skin contact and childcare articles. Children's exposure duration to textile apparel and home textiles (e.g. plaids and pillows) is deemed relevant within the scope of the present project.
(iii) Additive focus	
PAA in HDPE	Studies on migration of PAA from recycled plastic packaging to cosmetic simulant show measurable concentrations of PAA in the cosmetic simulant (Kastbjerg et al., 2021; Dahl et al., 2024). It may be relevant to investigate whether PAA in recycled plastic materials is a general issue and whether concentrations pose a health risk for consumers. Also, many more PAA exists than are regulated under REACH.
Analysis of stabilisers	A stakeholder mentioned that e.g., Irganox 1010 and Irgafos 168 are commonly used additives in both PIR and PCR plastic. This is supported by findings in the literature (Hahladakis et al., 2018). Some stabilisers also exhibit endocrine disrupting effects (Poulsen et al., 2020).
Metals in consumer products	Metals have been detected in different ranges in recycled PET, PP, PE, and PS (Eriksen et al., 2018). Investigation of the presence of metals in the final consumer product is of relevance to assess if they pose a health risk.
Benzotriazoles in consumer products	Emerging substance group of concern with four substances included in Annex XIV under REACH in 2024. No data has been identified on the presence of BUVs in consumer products of recycled plastic, however BUVs have been detected in virgin plastic bottles and packaging (two product types that are often recycled) as well as recycled plastic pellets. Hence, it may be relevant to investigate the presence of BUVs in consumer products. However, chemical analyses of benzotriazoles in consumer products have not been available in the analytical scope of the current project.

TABLE 3-1 divides the potential focus areas into three overall categories depending on the starting point in either (i) the type of plastic polymer, (ii) the type of product or (iii) the type of additive(s) used in the products.

A general challenge for category (i) and (iii) is that it is difficult to identify relevant articles on the market which contain a certain plastic polymer, since this information is often not available in the product descriptions. For example, for outdoor furniture and textiles, information about the polymer is often available, however, for other article groups such as toys or childcare articles, this information is typically not available. Therefore, in some cases a polymer analysis prior to chemical content analyses would be necessary, which is not feasible within the project scope. Hence, focus areas requiring a polymer analysis were excluded.

Moreover, it was deemed more relevant to conduct an exploratory investigation of possibly harmful chemicals in consumer products of recycled plastic, and not a targeted analysis of a specific substances/substance groups. This was prioritised in order to gain broader knowledge on the chemical content in consumer products of recycled plastic. Hence, category (iii) was excluded.

In collaboration with the Danish EPA, the final focus area was decided to be textile articles of recycled polyester or PET.

For the final selection of focus area, the following parameters were weighted:

- Price – Articles with lower prices allow for more samples within the project budget
- Exposure duration – Longer exposure times can be expected in the use of many textiles articles compared to other articles
- Sustainability claims – Many textile products are marketed as containing recycled plastic
- Type of plastic polymer – polyester or PET – is often specified in the marketing material of textile products, hence an additional polymer analysis is not necessary

3.2 Purchase of products

To investigate products with different exposure scenarios, it was decided to purchase 20 articles of the following categories:

- Home textiles for which children's exposure is likely (e.g., pillows, blanket)
- Children's outdoor clothing assumed to have limited skin contact (e.g., jackets)
- Children's clothing with direct skin contact (e.g., underwear)

Articles were searched for on the internet and purchased through online retailers. All products are made of at least 90% recycled plastic, and several products claim to be produced from recycled bottles i.e., PCR plastic.

At the time of purchase each product received a sample identification number (ID) with a letter depending on the textile category ("H" for home textile, "O" for outdoor clothing and "S" for clothing with skin contact) and the sample number. An overview of the purchased textiles as well as their sample IDs is presented in TABLE 3-2.

In order for the laboratory to analyse true duplicate samples, two specimens of each article were purchased. However, only one article was purchased of sample O-10 (rain poncho) and S-20 (t-shirt), as only one article was available for order at the time of purchase.

TABLE 3-2. Purchased textile products and their sample IDs.

Product category	Sample ID	Product
Home textiles	H-01	Plaid
	H-02	Plaid
	H-03	Plaid
	H-04	Pillow
	H-05	Pillow cover
	H-06	Rug
	H-07	Microfiber towel
Children's clothing, outer layer	O-08	Fleece jacket
	O-09	Fleece jacket
	O-10	Rain poncho
	O-11	Rain jacket
	O-12	Thermo jacket
	O-13	Thermo pants
Children's clothing with direct skin contact	S-14	Bathrobe
	S-15	Dress
	S-16	Boxer shorts
	S-17	Swim shorts
	S-18	Swim shorts
	S-19	Swimsuit
	S-20	T-shirt

3.3 Chemical screening analyses

3.3.1 Methods and sample preparation

Chemical analyses were conducted at the Danish Technological Institute. Two screening analyses were conducted: A semi-quantitative GC-MS screening to detect and quantify organic substances, as well as a semi-quantitative ICP-MS screening to detect and quantify metals.

Samples were taken from two specimens of each article for true duplicate determinations (except for sample O-10 and S-20, for which specimens were taken from the same article) and extracted with dichloromethane.

Semi-quantitative screening analyses quantitate the analytes relative to added internal standards. This type of quantification is subject to some uncertainty, which varies between the different analytes.

In the GC-MS screening, the uncertainty of each reported component was categorized in one of three identification levels:

- Category A: Confident and confirmed identification. The substance is identified by name, CAS no. (or NIST no. if CAS no. is not available for the substance in the library). It is noted that also for category A substances, some uncertainty remains regarding the precise substance identification.
- Category B: Partial identification. The substance is identified by chemical class of the compound, a fragment of the substance or by a compound bound to the substance.
- Category C: Unidentified substance.

A corresponding uncertainty categorization has not been available for the metals screening. More details on methods and sample preparation can be found in Annex 2.

3.3.2 Results

3.3.2.1 Results of the GC-MS screening

The GC-MS screening identified a total of 194 substances of which about 60% could be identified with confidence (TABLE 3-3).

TABLE 3-3. Number of substances per identification category in the GC-MS screening.

Category	Number of substances
Category A: Confident and confirmed identification	117 (60%)
Category B: Partial identification	32 (17%)
Category C: Unidentified substance	45 (23%)
Total	**194**

In the analysed articles, 11 – 23 substances could be identified per article, meaning that in none of the articles the number of identified substances exceeded 23 or fell below 11 (TABLE 3-4). The three articles containing more than 20 substances comprised both an outdoor article and two articles with direct skin contact. However, the differences are small and none of the articles stand out as containing especially many or few substances.

TABLE 3-4. Number of identified substances per article.

Article with identified substances per article	Number of articles	Product ID
Articles with >25 substances	0	-
Articles with >20-25 substances	3	O-13 S-16 S-19
Articles with >15-20 substances	8	H-03 H-05 H-06 O-10 O-11 S-14 S-17 S-20
Articles with >10-15 substances	9	H-01 H-02 H-04 H-07 O-08 O-09 O-12 S-15 S-18
Articles with ≤10 substances	0	-

An extract of the most frequently detected substances within the identification category A is provided in TABLE 3-5. An extract of the 10 substances found at the highest concentrations as well as their detection frequency is provided in TABLE 3-6. The 10 substances found with highest concentrations as well as number of their detections in the textile articles. The full list of analysis results is presented in Annex 3.

TABLE 3-5. Substances most frequently detected (in four or more articles) in the GC-MS screening. Please note that the given concentrations are semi-quantitative.

Substance	IUPAC name	CAS no.	No. of detections	Conc. max (mg/kg)	Detected in Product ID
13-Docosenamide, (Z)-	(Z)-docos-13-enamide	112-84-5	7	260	H-03 H-06 O-12 O-13 S-14 S-19 S-20
Benzenamine, 2-chloro-4,6-dinitro-	2-chloro-4,6-dinitroaniline	3531-19-9	5	270	H-05 O-08 O-13 S-15 S-16
1,4-Benzenedicarboxylic acid, bis(2-hydroxyethyl) ester	bis(2-hydroxyethyl) benzene-1,4-dicarboxylate	959-26-2	5	30	H-01 H-03 O-12 S-14 S-20
Decyl oleate	decyl (Z)-octadec-9-enoate	3687-46-5	4	230	H-04 O-12 O-13 S-19
9,10-Anthracenedione, 1-amino-4-hydroxy-2-phenoxy-	1-amino-4-hydroxy-2-phenoxyanthracene-9,10-dione	17418-58-5	4	120	O-09 O-10 S-18 S-20
2,6-Dichloro-4-nitroaniline	2,6-dichloro-4-nitroaniline	99-30-9	4	46	H-05 O-16 S-14 S-15
2-Ethylhexyl stearate	2-ethylhexyl octadecanoate	22047-49-0	4	40	H-04 S-14 S-16 S-17
n-Hexadecanoic acid	hexadecanoic acid	57-10-3	4	17	H-03 O-09 S-19 S-20

TABLE 3-6. The 10 substances found with highest concentrations as well as number of their detections in the textile articles. Please note that the concentrations are semi-quantitative.

Substance	IUPAC name	CAS no.	Conc. max (mg/kg)	No. of detections
1-Hydroxy-4-(p-toluidino)anthraquinone	1-hydroxy-4-(4-methylanilino)anthracene-9,10-dione	81-48-1	1600	1
2-(4-Acetylphenylamino)-1,4-naphthoquinone	2-(4-acetylanilino)naphthalene-1,4-dione	88590-25-4	520	2
Benzene, 1,1'-methylenebis[4-isocyanato-(MDI)	1-isocyanato-4-[(4-isocyanatophenyl)methyl]benzene	101-68-8	450	3
Benzene, 2,4-diisocyanato-1-methyl- (2,4-TDI)	2,4-diisocyanato-1-methylbenzene	584-84-9	380	2
Benzenepropanoic acid, 3-(1,1-dimethylethyl)-4-hydroxy-5-methyl-, 1,2-ethanediylbis(oxy-2,1-ethanediyl) ester	2-[2-[2-[3-(3-tert-butyl-4-hydroxy-5-methylphenyl)propanoyloxy]ethoxy]ethoxy]ethyl 3-(3-tert-butyl-4-hydroxy-5-methylphenyl)propanoate	36443-68-2	350	3
Benzyl Benzoate	benzyl benzoate	120-51-4	310	1
Benzenamine, 2-chloro-4,6-dinitro-	2-chloro-4,6-dinitroaniline	3531-19-9	270	5
13-Docosenamide, (Z)-	(Z)-docos-13-enamide	112-84-5	260	7
Decyl oleate	decyl (Z)-octadec-9-enoate	3687-46-5	230	4
2-Butenedioic acid (E)-, bis(2-ethylhexyl) ester	bis(2-ethylhexyl) (E)-but-2-enedioate	141-02-6	210	3

3.3.2.2 Results of the ICP-MS screening

The metal screening included 63 metals. The full list of analysis results is presented in Annex 3.

In the analysed articles, three – 12 metals could be identified per article. Only three articles contained detectable concentrations of more than 10 metals, comprising two home textile and one outdoor article (TABLE 3-7). However, the differences in the numbers are not substantial and thus, none of the articles stand out with respect to metal content.

TABLE 3-8 shows concentrations and detection frequency of 13 out of the 63 analysed metals, which are often recognized as hazardous or are part of a hazardous compounds.

TABLE 3-7. Number of identified metals per article.

Articles with identified number of metals	Number of articles	Product ID
Articles with >15 metals	0	-
Articles with >10-15 metals	3	H-03 H-06 O-11
Articles with >5-10 metals	7	H-01 H-02 O-10 O-13 S-15 S-18 S-19
Articles with 0-5 metals	10	H-04 H-05 H-07 O-08 O-09 O-12 S-14 S-16 S-17 S-20

TABLE 3-8. Concentrations and detection frequency of some metals in the ICP-MS screening. Concentration intervals (minimum to maximum) are given across samples. Please note that the given concentrations are semi-quantitative.

Metal	LOD (mg/kg)	Conc. min (mg/kg)	Conc. max (mg/kg)	No. of detections in articles	Product ID
Aluminum	50	98.6	143.0	3	H-03 H-06 O-11
Antimony	1.25	61.6	223.8	20	All
Arsenic	1.25	0.0	0.0	0	-
Cadmium	1.25	0.0	0.0	0	-
Chromium	1.25	0.0	0.0	0	-
Cobalt	1.25	1.4	1.4	1	H-01
Copper	1.25	0.0	0.0	2	H-03 O-10
Lead	1.25	0.0	0.0	0	-
Mercury	1.25	0.0	0.0	0	-
Molybdenum	1.25	0.0	0.0	0	-
Nickel	1.25	0.0	0.0	0	-
Tin	1.25	4.0	8.1	3	H-01 H-03 O-08

Metal	LOD (mg/kg)	Conc. min (mg/kg)	Conc. max (mg/kg)	No. of detections in articles	Product ID
Zinc	2.5	2.8	296.0	9	H-01 H-03 H-06 O-10 O-11 S-15 S-17 S-19 S-20

3.3.3 Discussion of chemical screening results

3.3.3.1 GC-MS screening

A total of 117 organic volatile and semivolatile substances could be with confidence identified (Category A) in the screening analysis.

These substances have been further reviewed and assessed by use of a hazard screening tool developed by the Danish EPA. With the excel-based tool, the identified substances are matched up against various lists of problematic substances e.g., the REACH Restriction List. The hazard screening tool allows for a swift evaluation of the substances detected in the analysed articles according to their health hazard. It is noted that the hazard screening tool has not been updated since 2021. However, as the tool is only used for an initial assessment of the detected substances, it was accepted that the tool has not been updated more recently.

The output from the hazard screening is due to its extent not available in this report. A comprehensive description of the excel tool can be found in section 3 of the Danish EPA report Antvorskov et al. (2023).

3.3.3.2 Metal screening

The findings of the metal screenings are compared to the findings in Eriksen et al. (2018) as reported in section 2.3.3.4.

Antimony was reported in the concentration ranges 271 – 304 mg/kg in PCR PET and 38 – 102 mg/kg in PIR PET in Eriksen et al. (2018). Hence, the antimony levels are comparable between the present study (62 – 224 mg/kg) and the findings in Eriksen et al. (2018). Antimony has a notified classification from a REACH joint submission as suspected carcinogen (Carc. 2, H351), reprotoxin (Repr. 1A, H360), and toxin following repeated inhalation (STOT RE 2, H373, lung). Antimony trioxide is a commonly used catalyst in the process of polyethylene terephthalate (PET) synthesis. Therefore, its presence in PET bottles and its migration potential to bottled water or other food stuff has been subject to earlier investigations (e.g., Carneado et al., 2023; Westerhoff et al., 2008).

Since the analysed textiles in the present project are made of PET, the presence of antimony may not be surprising. Additional investigations about antimony in recycled PET, e.g., regarding its leaching potential, its speciation in the textiles, whether content and leaching behaviour differ between virgin and recycled PET, will be valuable in order to assess any potential health risks related to the presence of antimony in recycled PET. However, such follow-up investigations exceed the scope of the current project and are therefore not pursued further here.

Regarding zinc, the concentrations found in the present study are lower than the values reported by Eriksen et al. (2018). In the present study, concentrations of up to 396 mg/kg zinc are reported, while Eriksen et al. (2018) report up to 660 mg/kg zinc in PIR and PCR PET.

There is no immediate explanation for the presence of zinc in the recycled PET but since zinc is an ubiquitously occurring and one of the most abundant elements, it is likely that the content origins from contamination. However, inorganic zinc does not have any obvious health hazards, and therefore its presence in the textile articles is not considered as concern.

Regarding the metals on the Restriction List under REACH, maximum concentration limits of 1 mg/kg apply to As, Cd, Hg and Pb in textiles (both clothing and textiles other than clothing). Using the ICP-MS method described previously, the LOD for the four metals was 1.25 mg/kg. None of the restricted metals were detected in the ICP-MS analysis.

For the remaining metals, no concentrations of concern were found in the ICP-MS analysis.

3.4 Migration analysis

3.4.1 Selection of substances for migration analyses

The objective of the migration analysis is to obtain data for the exposure assessment. In order to optimise resources, certain substances, articles and the type of migration simulation are prioritised among all substances, articles and migration simulation type.

Metals were omitted from the selection, as the results from the metals screening analysis do not indicate any immediate concern regarding the presence of the metals in the textiles. An exception is antimony; however, further investigation of this metal was not within the scope of the assignment. As mentioned in the previous section, none of the metals restricted under REACH have been detected in the ICP-MS analysis.

The substances for migration analyses are selected based on a prioritisation of the following:

a. Substances found at “increased” concentrations in relation to the substance concentrations found in general in the articles
b. Substances detected most often in the articles
c. Presence on SVHC list (hazard screening tool)
d. Presence on Annex XVII of REACH (hazard screening tool)
e. Harmonised or notified classification as endocrine disrupting (ED1, ED2), CMR, STOT RE and/or Allergy (hazard screening tool)

For each of the listed criteria, the substance was assigned points, which were summed to an overall score.

The eight most relevant substances detected in the GC-MS screening of the 20 textile samples containing recycled PET/polyester are presented in TABLE 3-9. In the table, the substances are ranked according to their score. The score has been assessed by assigning one point if the substance was detected in a concentration of more than 100 mg/kg (>0.01%), one point if the substance was detected in more than 3/20 products, one point if the substance was listed as SVHC or in Annex XVII to REACH, and 1 point per classification list (regardless of whether the classification was harmonised or not). The hazard screening tool includes five classification lists (ED1, ED2, CMR, STOT RE, Allergy). All the listed substances belong to identification category A (as described in section 3.3.1) with a LOD of 5 mg/kg.

Since the hazard screening tool was last updated in 2021, the regulation status of the listed substances was doublechecked and updated according to their current status in the ECHA chemicals database. Here it was found that diethyl phthalate (CAS no. 84-66-2) is not listed as a SVHC nor in Annex XVII. The correct score of diethyl phthalate would therefore be 2 (and not 3), and the substance was excluded from the selection for migration analysis. For phenol, 4,4-(1-methylethylidene)bis-, (BPA; CAS no. 80-05-7), it was found that the listings in the hazard tool were not aligned with its regulatory status under REACH (see TABLE 3-9). During the past years, the focus on BPA in consumer products has increased, and hence, it is of interest whether this substance occurs in products of recycled plastic. Therefore, BPA was included for migration analysis.

In summary, the following eight substances are selected for the migrations analyses:

- 9,10-Anthracenedione, 1-amino-4-hydroxy-2-phenoxy-, CAS no. 17418-58-5
- Benzene, 1,1'-methylenebis[4-isocyanato-, CAS no. 101-68-8
- Benzenamine, 2-chloro-4,6-dinitro-, CAS no. 3531-19-9
- Benzene, 2,4-diisocyanato-1-methyl-, CAS no. 584-84-9
- Benzene, 1,3-diisocyanato-2-methyl-, CAS no. 91-08-7
- 2,6-Dichloro-4-nitroaniline, CAS no. 99-30-9
- 1-Hydroxy-4-(p-toluidino)anthraquinone, CAS no. 81-48-1
- Phenol, 4,4-(1-methylethylidene)bis-, CAS no. 80-05-7

Based on the substances' occurrence and concentrations in the articles, the following nine articles, were selected for migration analyses:

- H-01, H-05 (plaid, pillow cover)
- O-08, O-10, O-11 (fleece jacket, rain poncho, rain jacket)
- S-15, S-16, S-18, S-20 (dress, boxershorts, swim shorts, t-shirt)

The listed articles containing the prioritised substances are intended for children (with the exception of H-01 and H-05) but not specifically toddlers. Considering the intended use of the articles and intended user group for most of the articles (>2 years), oral exposure is considered less relevant compared to dermal exposure. Thus, the migration analyses will use a sweat simulant to generate data for the dermal exposure assessment.

TABLE 3-9. Priority substances from the GC-MS screening

Substance	CAS no.	Score [1]	Listed in hazard tool	Listed currently as SVHC, Annex XVII and classification in C&L inventory	Conc. min (mg/kg)	Conc. max (mg/kg)	No. of detections	Product ID	Product
9,10-Anthracenedione, 1-amino-4-hydroxy-2-phenoxy-	17418-58-5	5	SVHC, XVII Har. Class.: ED1 Self-class.: CMR	Self-class.: Skin Sens. 1A	8.2	120	4	O-09 O-10 S-18 S-20	Fleece jacket Rain poncho Swim shorts T-shirt
Benzene, 1,1'-methylenebis[4-isocyanato-	101-68-8	4	Har. Class.: CMR STOT RE Allergy	XVII Har. Class.: Skin Sens. 1 CMR STOT RE 2	11	450	3	O-10 O-11 S-19	Rain poncho Rain jacket Swimsuit
Benzenamine, 2-chloro-4,6-dinitro-	3531-19-9	3	Self-class.: CMR	Self-class.: CMR STOT RE 2	10	270	5	H-05 O-08 O-13 S-15 S-16	Pillow cover Fleece jacket Thermo pants Dress Boxer shorts
Benzene, 2,4-diisocyanato-1-methyl-	584-84-9	3	Har. Class.: CMR Allergy	XVII Har. Class.: Skin Sens. 1 CMR	12	380	2	O-10 O-12	Rain poncho Thermo jacket
Benzene, 1,3-diisocyanato-2-methyl-	91-08-7	3	Har. Class.: CMR Allergy	XVII Har. Class.: Skin Sens. 1 CMR	120	120	1	O-10	Rain poncho
2,6-Dichloro-4-nitroaniline	99-30-9	3	Har. Class.: ED2 Self-class.: CMR	Self-class.: STOT RE 2	3	46	4	H-05 O-08 S-14 S-15	Pillow cover Fleece jacket Bathrobe Dress
Diethyl Phthalate [2]	84-66-2	3	SVHC, XVII Har. Class.: ED1 Self-class.: CMR	Self-class.: STOT RE 2 CMR Skin Sens. 1	17	17	1	S-17	Swim shorts
1-Hydroxy-4-(p-toluidino)anthraquinone	81-48-1	3	Self-class.: CMR Allergy	Self-class.: Skin Sens. 1B	1600	1600	1	O-11	Rain jacket
Phenol, 4,4-(1-methylethylidene)bis- [2]	80-05-7	2	CMR, Allergy	SVHC, XVII Har. Class.: Repr. 1B Skin Sens. 1	4.6	21	2	H-01 S-20	Plaid T-shirt

[1] Score is given as follows: 1 point if concentration > 100; 1 point if no. of detections > 3; 1 point if substance is SVHC or in Annex XVII; 1 point per classification (ED1, ED2, CMR, STOT RE, Allergy (Sens.)). Self-classification and harmonized classification are weighted equally.

[2] Diethyl phthalate replaced by Phenol, 4,4-(1-methylethylidene)bis- (BPA). See text for elaboration of substance selection for migration analysis.

3.4.2 Methods and sample preparation

The migration analysis was conducted at the Danish Technological Institute.

Samples were taken from two specimens of each article for true duplicate determinations (except for sample O-10 and S-20, for which specimens were taken from the same article).

Following standard procedure DS/EN 1811, samples were placed in artificial sweat simulant for 12 hours at 37 °C while shaking at 90 rpm. The analysis parameters for the migration analysis were chosen to mimic a realistic worst-case scenario of exposure. Hence, the selected temperature corresponds to body temperature, while the exposure duration was selected to account for the long but not unrealistic exposure to the products . Moreover, the migration analysis was performed under dynamic conditions (shaking) to reflect movement during exposure.

Hereafter, migration of substances into the artificial sweat simulant was measured by extracting the migration liquid with dichloromethane containing internal standards. The dichloromethane phase was then analysed by LV-GC/MS[17] and findings were quantified using authentic standards.

3.4.3 Results

Results from the migration analysis are given in TABLE 3-10.

Of the eight tested substances only three (approximately 40%) were measured above the limit of detection in sweat simulant: 2,4-toluene diisocyanate (2,4-TDI), 2,6-toluene diisocyanate (2,6-TDI), and 4,4'-methylenediphenyl diisocyanate (MDI).

In practice, 2,4-TDI and 2,6-TDI is a commercial mixture, known as 2,4-/2,6-toluene diisocyanate mixture – or just TDI (CAS no. 26471-62-5) (Vium et al., 2015). Both isomers and the mixture have the same EU harmonised classification. Thus, 2,4-TDI and 2,6-TDI will be discussed as one substance – TDI – in the following text.

Contents of both TDI and MDI were detected to have migrated from sample O-10 (a rain poncho), while MDI was also detected to have migrated from sample O-11 (a rain jacket). From the other samples, none of the target chemicals were measured above the limit of detection.

[17] Large-volume gas chromatography coupled to mass spectrometry.

TABLE 3-10. Results from the migration analysis. Findings are reported for the respective samples in mg/kg and $mg/cm^2/12$ h.

			Detected concentrations that have migrated from samples [mg/kg] / [mg/cm²/12 h]								
Substance	**CAS no.**	**LOD [mg/kg] / [mg/cm²/12 h]**	**H-01**	**H-05**	**O-08**	**O-10**	**O-11**	**S-15**	**S-16**	**S-18**	**S-20**
Benzene, 1,3-diisocyanato-2-methyl- (2,6-TDI)	91-08-7	5 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	56 / 4.8×10^{-4}	<LOD	<LOD	<LOD	<LOD	<LOD
Benzene, 2,4-diisocyanato-1-methyl- (2,4-TDI)	584-84-9	5 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	103 / 8.8×10^{-4}	<LOD	<LOD	<LOD	<LOD	<LOD
2,6-Dichloro-4-nitroaniline	99-30-9	5 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzenamine, 2-chloro-4,6-dinitro-	3531-19-9	1 / $9.0\times10^{-6} – 5.0\times10^{-5}$	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzene, 1,1'-methylenebis[4-isocyanato- (MDI)	101-68-8	1 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	2.1 / 1.8×10^{-5}	21 / 2.1×10^{-4}	<LOD	<10 / <4.0×10^{-4} [a]	<LOD	<LOD
Phenol, 4,4'-(1-methylethylidene)bis-	80-05-7	5 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
9,10-Anthracenedione, 1-amino-4-hydroxy-2-phenoxy-	17418-58-5	5 / $5.0\times10^{-5} – 3.0\times10^{-4}$	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
1-Hydroxy-4-(p-toluidino)anthraquinone	81-48-1	10 / $9.0\times10^{-5} – 5.0\times10^{-4}$	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

[a] The limit of detection was raised to 10 mg/kg / 4.0×10^{-4} for this sample due to matrix interference. Hence this finding is <LOD.

3.4.4 Discussion of migration analysis results

Only three out of eight substances that were measured in the GC-MS screening and prioritised for migration analysis were actually detected in the migration analyses. Moreover, the concentrations of the concentration of the detected and quantified substances (the isocyanates) were lower compared to the concentrations measured in the GC-MS screening. There are two reasons for this; firstly and most importantly, for the GC-MS screening, substances in the samples were extracted directly using a strong solvent (dichloromethane) which efficiently extracts substances from the samples. In the migrations analysis, the samples were extracted using artificial sweat, which is a mild solvent compared to dichloromethane. Secondly, it has to be noted, that there is considerable uncertainty related to the reported concentrations from the GC-MS screening, as substance-specific standards were not included and the reported concentrations are semi-quantitative.

The substances detected in the migration analysis, MDI and TDI, are both isocyanates, which are usually associated with PU material (Sharmin and Zafar, 2012). Isocyanates have been detected in previous investigations on consumer products, in squishies and PU foam mattresses (Klinke et al., 2018; Kjølholt et al., 2015; Vium et al., 2015). According to the information provided by the distributors, the analysed products are manufactured of 100% recycled polyester sourced from PET bottles or textile waste, and not of PU material.[18]

Reasons for findings of isocyanates could be surface treatments with PU-based coatings (containing isocyanates), which may be used to improve the properties of the textile products, e.g., waterproofness, durability, or flexibility. Isocyanates can also be used as polymerisation additives (chain extenders) in both virgin PET and/or rPET for improving PET polymer properties (Vozniak et al., 2024; Çavuşoğlu and Acar, 2023; Torres et al., 2001).

Isocyanates could also arise from glue used for assembling different layers of textile material or for fixation of decorations or labels to polyester fabric. Even though glued seams were not included when cutting the textile samples, it cannot be excluded that samples have been contaminated with adhesives, in which isocyanates are commonly used (Liu et al., 2013).

Additionally, a reason for the findings of isocyanate may be that the given information on the product material composition may be inaccurate or misleading (i.e. that the article does not consist of 100% recycled PET).

Apart from the intentional addition of isocyanates in the recycling process, a source of isocyanates could also be contamination of the PET bottles or textile waste during the collection, recycling, or re-compounding phases of the plastic life cycle (denoted by blue arrows in FIGURE 1.

The latter possible explanation relates to the recycling – the remaining possible reasons for why isocyanates are present in the PET articles are not specific for textiles made of recycled plastic, meaning that isocyanates could just as well be present in textiles made of virgin plastic.
The concentration of MDI in consumer products is restricted according to entry 56 in Annex XVII to REACH regulation 1907/2006.[19] However, none of the findings in the migration analysis nor in the GC-MS screening exceed the MDI concentration limit value of 0.1% by weight (corresponding to 1,000 mg/kg). TDI is also restricted with a concentration limit of 0.1%

[18] According to distributor's websites both products were manufactured from 100% recycled polyester sourced from PET bottles or textile waste. O-11 was further treated with a "non-PFAS BIONIC-FINISH® ECO" coating.
[19] https://echa.europa.eu/documents/10162/a3af0497-4775-1a05-7037-80d653a39272

by weight through entry 74 in Annex XVII to REACH, however, only for industrial and professional use.[20] No concentration limit values exist for TDI in consumer products.

3.5 Conclusion on chemical analyses

The GC-MS screening identified a total of 194 substances of which about 60% (117 substances) could be identified with confidence. Most textile articles (17 out of 20) contained between 11-20 substances. Based on the substance's concentrations, their number of detections, their hazard properties (health hazard classification) and regulatory status (listed on Annex XVII of REACH and/or SVHC list), eight substances and nine articles were prioritised for further investigation via migration analysis.

Additionally, the presence of three – 12 metals could be identified per article in the ICP-MS screening. Overall, the concentrations of the metals found in the screening analysis did not cause concern with the exception of measured levels of antimony. Further investigation of content, speciation and leaching behaviour of antimony in recycled PET would be valuable in order to assess any potential health risks related to the presence of antimony in recycled PET.

Of the eight substances included in the migration analysis, only three were measured above the limit of detection in sweat simulant: 2,4-toluene diisocyanate (2,4-TDI), 2,6-toluene diisocyanate (2,6-TDI), and 4,4'-methylenediphenyl diisocyanate (MDI). These three substances belong to the chemical group of isocyanates that are usually associated with PU, not PET, articles. Their presence cannot be interpreted as being specific for textiles made of recycled PET.

The concentrations and numbers of detected substances in the migration analysis were lower than concentrations and numbers of detected substances in the screening analysis. A plausible reason for this is that the water-based sweat simulant is not as efficient for extracting substances as the solvent dichloromethane, which was used in the screening analysis. However, using sweat simulant reflects a more realistic dermal exposure via sweating. The results from the screening and migration analyses thus show, that even though many substances may be present in textiles made of recycled PET, dermal exposure via sweat as simulated in the migration analysis will only occur for a smaller fraction (in this study, ca. 40%) of these substances.

The substances detected in the migration analysis are assessed in the following hazard, exposure, and risk assessment of substances in recycled plastic products.

[20] https://echa.europa.eu/documents/10162/503ac424-3bcb-137b-9247-09e41eb6dd5a

4. Hazard, exposure, and risk assessment

4.1 Hazard assessment

As only the substances toluene diisocyanate (TDI – a mixture of the isomers 2,4-toluene diisocyanate and 2,6-toluene diisocyanate) and 4,4'-methylenediphenyl diisocyanate (MDI) were detected in the migration analysis, both substances/mixtures are selected for hazard assessment.

In the following sections, the isocyanates are described in terms of their harmonised classification according to the CLP Regulation (1272/2008), their physicochemical properties as well as their toxicity. Substance toxicity is investigated with focus on children's dermal exposure through a targeted review of grey literature and authority evaluations of the substances.

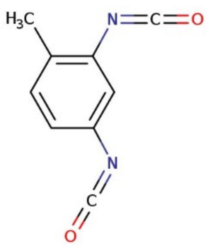
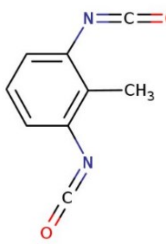
4.1.1 Toluene diisocyanate (TDI)

4.1.1.1 Substance use and physicochemical properties

TDI is applied in the manufacture of PU foam and paints as well as elastomers and coatings (PubChem 2024a; 2024b).

TABLE 4-1 provides information on the identification, physicochemical properties as well as the EU harmonised classification[21,22] (according to CLP Regulation (1272/2008)) of both isomers of TDI.

TABLE 4-1. Identification and physicochemical properties of both isomers of TDI.

Parameter	Description of isomers constituting TDI (CAS no. 26471-62-5)		Source
Substance name in laboratory reporting	Benzene, 2,4-diisocyanato-1-methyl-	Benzene, 1,3-diisocyanato-2-methyl-	Laboratory reporting
IUPAC name	2,4-toluene diisocyanate (2,4-TDI)	2,6-toluene diisocyanate (2,6-TDI)	ECHA Substance Infocard
CAS no.	584-84-9	91-08-7	ECHA CHEM
Structure			ECHA CHEM
Chemical group	Isocyanates	Isocyanates	
Vapour pressure (interpretation)	14 – 21 Pa at 20 °C (volatile)	2.78 Pa at 25 °C (non-volatile)	ECHA CHEM
Molecular weight	174.16 g/mol	174.16 g/mol	PubChem (2024a; 2024b)

[21] ECHA C&L inventory, accessed 01.11.2024. URL: https://echa.europa.eu/da/information-on-chemicals/cl-inventory-database/-/discli/details/35640
[22] ECHA C&L inventory, accessed 01.11.2024. URL: https://echa.europa.eu/da/information-on-chemicals/cl-inventory-database/-/discli/details/43530

Parameter	Description of isomers constituting TDI (CAS no. 26471-62-5)		Source
LogPow	3.43 at 22 °C	3.74	ECHA CHEM
Harmonised CLP classification	Skin Irrit. 2 – H315 Eye Irrit. 2 – H319 Skin Sens. 1 – H317 Acute Tox. 2 – H330 STOT SE 3 – H335 Resp. Sens. 1 – H334 Carc. 2 – H351 Aquatic Chronic 3 – H412 Specific concentrations limits: Resp. Sens. 1; H334: C ≥ 0.1 %	Skin Irrit. 2 – H315 Eye Irrit. 2 – H319 Skin Sens. 1 – H317 Acute Tox. 2 – H330 STOT SE 3 – H335 Resp. Sens. 1 H334 Carc. 2 – H351 Aquatic Chronic 3 – H412 Specific concentrations limits: Resp. Sens. 1; H334: C ≥ 0.1 %	ECHA C&L inventory

4.1.1.2 Substance toxicity

As shown in TABLE 4-1, there are harmonised classifications for TDI on a range of endpoints, including dermal and inhalational irritation and sensitisation as well as carcinogenicity. Several sources for describing the substance toxicity have been consulted, amongst them two earlier reports by the Danish EPA (Christensen et al., 2014; Vium et al, 2015), the background document for the restriction proposal for diisocyanates (ECHA, 2018b) as well as the scientific evaluation of occupational exposure limits by RAC (ECHA, 2020). None of these sources (Christensen et al., 2014; Vium et al, 2015, ECHA, 2018b or ECHA, 2020) addresses the carcinogenic properties of the substance in their hazard assessments, even though the harmonized classification indicates TDI as suspected of causing cancer. It has not been possible to find the background data for the decision on the CLH and inclusion in Annex VI to CLP.

For professionals, the most critical effect of TDI is respiratory sensitisation, for which no lower threshold can be defined (ECHA 2018b). Several sources (Pawlak et al., 2024; NICNAS, 2020) report TDI to be hazardous towards workers, and the professional use of TDI has been restricted through entry 74 in Annex XVII in the REACH regulation (the restriction covers diisocyanates as a group, including TDI). Thus, the limit value for use of diisocyanates, including TDI, for industrial or professional uses is 0.1% by weight unless workers have "*successfully completed training on the safe use of diisocyanates*".[23] Even though the primary health concern lifted in entry 74 is the respiratory sensitisation, the RAC background (ECHA, 2018b) document for the opinion on diisocyantes assumes that the proposed measures will reduce the established risk of respiratory sensitisation as well as any other potential health risks, including any concerns about carcinogenicity. According to the RAC opinion, it is not possible to derive any DNEL values based on the available data (ECHA, 2018b). In the ECHA CHEM disseminated information on the substance on the other hand, inhalational DNELs are provided for workers, but this is the only route of exposure considered. In the toxicological information summary on the substance, the REACH registrants conclude no repeated dose dermal toxicity studies are available for TDI. It is stated that the skin penetration of TDI is low and a dermal DNEL for systemic toxicity (short-term and long-term) is therefore not derived. This is also in line with conclusions drawn by Vium et al (2015) stating that TDI is a reactive substance and the systemic effect from dermal exposure is expected to be limited.

For consumers, data on the hazardous endpoints relevant for consumer uses – and hence the most critical effect – is more limited. Looking up the CAS numbers for the TDI isomers in ECHA CHEM shows that there are no active dossiers for 2,6-TDI, whereas there are active dossiers for 2,4-TDI as well as the mixture of the two TDI isomers 2,4-TDI and 2,6-TDI under CAS number 26471-62-5. However, as reported by Christensen et al. (2014), no derived no-effect levels (DNELs) are provided for consumer exposure to TDI in any of the REACH dossiers. The disseminated parts of the substance information in ECHA CHEM indicates skin

[23] https://echa.europa.eu/documents/10162/503ac424-3bcb-137b-9247-09e41eb6dd5a

sensitizing properties for each of the isomers as well as the mixture. This is described in the robust study summaries on several *in vivo* skin sensitization tests, but not detailed enough to use as point of departure for DNEL derivations. As stated by Christensen et al. (2014) "*it appears strange that no dermal DNEL is in place, (…) although inhalation must indeed be assumed to be a key exposure route for the volatile TDI.*"

Another investigation performed by Vium et al. (2015) on behalf of the Danish EPA reports quantitative DNEL values for skin irritation and skin sensitisation. These are shown in TABLE 4-2. The DNEL values are based on human LOAELs derived by Arnold et al. (2012).

TABLE 4-2. DNEL values for TDI (Arnold et al., 2012 cited in Vium et al., 2015).

Endpoint	Type of value	Value	Assessment factor	DNEL	Comment
Skin irritation	Human LOAEL	600 μg/cm^2	3	200 μg/cm^2	Value will not be applied in the current risk assessment as it was disregarded by RAC (see text)
Skin sensitisation	Mouse, EC3	5 μg/cm^2	15	0.33 μg/cm^2	Value will not be applied in the current risk assessment as it was disregarded by RAC (see text)

It should be noted that the above DNEL values for skin irritation and skin sensitisation have not been considered in the opinion on an Annex XV dossier proposing restrictions for diisocyanates of the Risk Assessment Committee (RAC) and Committee for Socio-economic Analysis (SEAC) on (ECHA, 2018b). In fact, RAC (ECHA, 2018b) argues that: *"There is no available information on health risk of application of diisocyanates-containing products by consumers (Lockey et al. 2015; Verschoor and Verschoor 2014; and Web of Science-all databases (literature search performed by the rapporteurs)), and no new information on exposure and health risks related to consumer use of diisocyanates was provided during the Public Consultation. RAC, therefore, agrees with the Dossier Submitter's justification for omitting the diisocyanate-containing consumers' product from the scope of this restriction proposal, but stresses that this issue should be reconsidered when more information on exposure and health risk in consumers becomes available."*
Based on the argumentation by RAC, the above DNELs are not considered appropriate for conducting a quantitative risk assessment on consumer hazard. A quantitative risk assessment is therefore not conducted for TDI.

The ECHA guidance on risk characterisation (Part E, chapter 3.4.1 in ECHA 2016b) states that a qualitative risk assessment is needed for substances with sensitizing and/or carcinogenic properties. A qualitative risk assessment is therefore proposed in the following section 4.3, to cover any potential risks related to the hazard endpoints considered most relevant for consumer exposure in this project: skin irritation, skin sensitization and carcinogenicity.

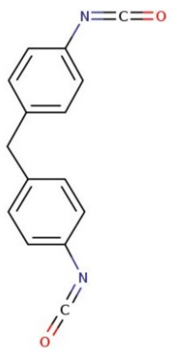
4.1.2 4,4'-Diphenylmethane diisocyanate (MDI)

4.1.2.1 Substance use and physicochemical properties

MDI is applied for the manufacture of PU foams (PubChem, 2024c).

TABLE 4-3 provides information on the identification, physicochemical properties as well as the EU harmonised classification[24] (according to CLP Regulation (1272/2008)) of MDI.

TABLE 4-3. Identification and physicochemical properties of 4,4'-MDI.

Parameter	Description	Source
Substance name in laboratory reporting	Benzene, 1,1'-methylenebis[4-isocyanato-	Laboratory reporting
IUPAC name	4,4'-Diphenylmethane diisocyanate	ECHA Substance Infocard
Other name	4,4'-methylenediphenyl diisocyanate (MDI)	ECHA CHEM
CAS no.	101-68-8	ECHA CHEM
Structure		ECHA CHEM
Chemical group	Isocyanates	
Vapour pressure (interpretation)	0.001 Pa at 20 °C (non-volatile)	ECHA CHEM
Molecular weight	250.25 g/mol	PubChem
LogPow	No data	ECHA CHEM
Harmonised CLP classification	Skin Irrit. 2 – H315 Eye Irrit. 2 – H319 Skin Sens. 1 – H317 Acute Tox. 4 – H332 STOT SE 3 – H335 Resp. Sens. 1 H334 Carc. 2 – H351 STOT RE 2 – H373 Specific concentrations limits: Eye Irrit. 2; H319: C ≥ 5 % Resp. Sens. 1; H334: C ≥ 0,1 % STOT SE 3; H335: C ≥ 5 % Skin Irrit. 2; H315: C ≥ 5 %	ECHA C&L inventory

4.1.2.2 Substance toxicity

As shown in TABLE 4-1, there are harmonised classifications for MDI on a range of endpoints, including dermal and inhalational irritation, sensitisation as well as carcinogenicity. No one of the consulted data sources (Christensen et al., 2014 or Health Board Estonia, 2018) addresses the carcinogenic properties of the substance in their hazard assessments, even though the harmonized classification indicates MDI as suspected of causing cancer. It has not been possible to find the background data for the decision on the CLH and inclusion in Annex VI to CLP.

[24] ECHA C&L inventory, accessed 01.11.2024. URL: https://echa.europa.eu/da/information-on-chemicals/cl-inventory-database/-/discli/details/5150

MDI is included in the restriction of diisocyanates through entry 74 in Annex XVII to the REACH regulation, together with TDI.[25] The primary health concern lifted in this entry is the respiratory sensitisation but in the ECHA (2018b) background document for the opinion on diisocyantes' other potential health hazards, such as carcinogenicity, are also mentioned. However, according to the RAC opinion, it is not possible to derive any DNEL values based on the available data (ECHA, 2018b).

Moreover, MDI is regulated through entry 56 in Annex XVII to the REACH regulation, which defines a concentration limit for MDI of 0.1% by weight in mixtures intended for consumer use.[26] The restriction does not state any background or argumentation for the limit value.

Christensen et al. (2014) report DNELs for acute toxicity (dermal) for consumers (systemic effects 50 mg/kg bw/day and local effects 17.2 mg/cm²) based on information from the ECHA dossier on MDI; however, the data cannot be validated, because the information is not justified in the ECHA dossier (as previously mentioned; Christensen et al., 2014). Hence, the values cannot be used for risk assessment. The disseminated parts of the substance information in ECHA CHEM indicates skin sensitising properties from several *in vivo* skin sensitisation tests as well as human data. In the REACH dossier, the hazard assessment for general population concludes "*no reliable dose descriptors can be derived for dermal and ocular irritation and for skin sensitization via the skin".* As parts of the dossier are confidential, it is not possible to validate this statement, nor derive any DNEL values based on any findings presented in ECHA CHEM.

MDI was evaluated under the CoRAP by the eMSCA Estonia[27] (Health Board Estonia, 2018). In the evaluation, critical worker DNEL(s) were identified for carcinogenicity and irritation of the respiratory tract upon inhalation but no DNELs for dermal exposure were identified. The eMSCA also concluded that there was no concern for consumer exposure and no need for regulatory follow-up action at EU level.

Based on the lack of any reliable hazard data on the substance, no DNELs are identified for use in a quantitative risk assessment on consumer hazard. A quantitative risk assessment is therefore not conducted for MDI. The ECHA guidance on risk characterisation (Part E, chapter 3.4.1 in ECHA 2016b) states that a qualitative risk assessment is needed for substances with sensitizing and/or carcinogenic properties. A qualitative risk assessment is therefore proposed in the following section 4.3, to cover any potential risks related to the hazard endpoints considered most relevant for consumer exposure in this project: skin irritation, skin sensitization and carcinogenicity.

4.2 Exposure assessment

In the following sections, the potential exposure to the substances identified in the migration analysis is described. The exposure assessment follows a tiered approach in which calculations assume worst-case scenarios. If the assumptions used in the worst-case scenarios indicate a risk, the scenarios will be refined using more realistic assumptions. If the worst-case scenarios do not indicate a risk, no further calculations will be carried out.

4.2.1 Relevant exposure pathway and group

The scope of the project is to assess exposure to potentially harmful chemicals from consumer products that children may encounter and be exposed to – but are not necessarily marketed

[25] https://echa.europa.eu/documents/10162/503ac424-3bcb-137b-9247-09e41eb6dd5a
[26] https://echa.europa.eu/documents/10162/a3af0497-4775-1a05-7037-80d653a39272
[27] Community rolling action plan (CoRAP), evaluating Member State Competent Authority (eMSCA). https://echa.europa.eu/de/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table

for children. Based the textile articles selected and analysed (chapter 3), the relevant exposure group is identified to be young children aged 2 – <6 years (categorised according to ECHA, 2017).

As described in section 3.4.1, the exposure assessment focused on assessing exposure via the dermal route based on the use of the textile articles. Even though oral or inhalation exposure may occur, these exposure routes were considered less relevant compared to dermal exposure and not prioritised in the analytical budget and the scope of the risk assessment in this study.

4.2.2 Exposure calculation method

The exposure assessment follows the principles set out in the ECHA guidance document “Guidance on Information Requirements and Chemical Safety Assessment, Chapter R.15: Consumer Exposure Assessment” (ECHA, 2016).

The dermal exposure to an article – e.g., a textile can be calculated based on results from migrations analysis and using the following equations and parameters in TABLE 4-4 (ECHA, 2016a; Kjølholt et al., 2015).

$$L_{der} = Migr \times T_{contact} \quad \textbf{Equation 4-1}$$

$$D_{der,external} = \frac{L_{der} \times A_{skin} \times n}{BW} \quad \textbf{Equation 4-2}$$

TABLE 4-4. Parameters used in the exposure estimation for dermal absorption of substances in textiles (ECHA, 2016a; Kjølholt et al., 2015).

Parameter	Description	Unit
A_{skin}	Surface area of the exposed skin (see TABLE 4-5)	cm^2
BW	Body weight (Assumed to be 15.6 kg for young children according to ECHA (2017))	kg
$D_{der,external}$	Dermal dose (external): Amount of substance per bodyweight that can potentially be absorbed	mg/kg bw/d
L_{der}	Dermal load: Amount of substance per unit skin area	mg/cm^2
Migr	Amount of substance migration to artificial sweat per surface area of the product on the skin per unit of time	$mg/cm^2/h$
n	Frequency of use; mean number of events per day (Assumed to be 1)	/d
$T_{contact}$	Duration of contact between article and skin per event (12 h according to the test conditions described in section 3.4.2)	h

According to the ECHA guidance document, the dermal load is expressed as “*the amount of substance per unit surface area of skin exposed*” (ECHA, 2016a) and can be calculated from the substance concentration in the product. Here, the equation has been adjusted in accordance with the method applied by Kjølholt et al. (2015). This is done to account for the fact that migration concentrations, and not only measured concentrations of substances in the textiles, are available. This method is deemed more appropriate as migration into sweat is considered to represent a more realistic exposure to the substance. In the calculations the values reported in TABLE 3-10 denote the dermal load, since the migration results already account for the exposure time of 12 hours.

The dermal load is hereafter used to derive the external dermal dose, which is the amount of substance per bodyweight that can potentially be taken up through the skin over time (Equation 4-2).

The skin area data for young children aged 2-6 years, used as input parameter for derivation of the dermal dose, are provided in TABLE 4-5 in accordance with recommendation no. 14 of the Biocidal Product Committee Ad hoc Working Group on Human Exposure on “Default human factor values for use in exposure assessments for biocidal products”[28] (ECHA, 2017). As a worst-case scenario, direct skin contact is assumed in the calculations, i.e., trunk and arms are exposed directly when wearing a jacket. Furthermore, the mean bodyweight of a young child is assumed to be 15.6 kg according to the ECHA recommendation (ECHA, 2017).

TABLE 4-5. Skin area of young children aged 2 – <6 years (Appendix A in ECHA, 2017).

Body part	Skin area (cm^2)
Head (face)	523.6
Trunk	2774.4
Arms	945.2
Upper arms	573.5
Forearms	371.7
Hands (fronts and backs)	330.9
Legs	1797.5
Thighs	1049.5
Lower legs	748
Feet	428.4
Total	**6800**

If the external dermal dose indicates a risk, the calculation can be further refined by accounting for the fact that the exposed skin area is most likely not the entire upper body, but rather forearms only.

4.2.3 Exposure to MDI and TDI

Using the above equations and the results from the migration analysis given in TABLE 3-10, the exposure to the detected isocyanates is calculated. As migration of substances was only found to occur from two textile articles, results from only those samples (O-10 and O-11) are included in the exposure assessment.

Exposure to TDI is calculated as the sum of exposure to 2,4-TDI and 2,6-TDI. Both isomers were detected in sample O-10 (a rain poncho). An example of the exposure calculation is provided in the following. Note that the dermal load is not multiplied by the exposure time, as the results in TABLE 3-10 are already given for the 12 hours exposure duration.

$$L_{der} = 4.8 \times 10^{-4}\ \mathrm{mg/cm^2} + 8.8 \times 10^{-4}\ \mathrm{mg/cm^2} = 1.36 \times 10^{-3}\ \mathrm{mg/cm^2}$$

$$D_{der,external} = \frac{1.36 \times 10^{-3}\ \frac{\mathrm{mg}}{\mathrm{cm^2}} \times (2774.4\ \mathrm{cm^2} + 945.2\ \mathrm{cm^2}) \times 1/\mathrm{d}}{15.6\ \mathrm{kg\ bw}} = 0.32\ \mathrm{mg/kg\ bw/d}$$

The dermal loads (L_{der}) and dermal doses (D_{der}) of the respective findings in the textile samples are given in TABLE 4-6.

[28] Although the recommendation relates to exposure assessments for biocidal products, the ECHA guidance document (ECHA, 2016a) refers to the recommendation for default human factor values for exposure assessment.

TABLE 4-6. Worst-case scenario dermal loads (L_{der}) and dermal doses (D_{der}) of TDI and MDI in the respective samples with findings. Input parameters for the calculations are also given. The skin area is the sum of the area of trunk and arms given in TABLE 4-5.

Substance	Sample	Skin area (cm^2)	BW	Migr / 12 h [mg/cm^2]	L_{der} [mg/cm^2]	$D_{der, external}$ [mg/kg bw/d]
TDI	O-10	3719.6	15.6	1.1×10^{-4}	1.4×10^{-3}	0.32
MDI	O-10	3719.6	15.6	1.5×10^{-6}	1.8×10^{-5}	0.0043
MDI	O-11	3719.6	15.6	1.9×10^{-5}	2.3×10^{-4}	0.055

As both textiles articles (rain poncho and rain jacket) are outerwear, it is more realistic to assume that another layer of clothes is worn between the skin and the jacket/poncho. Hence, conducting the same calculations as above but adjusting the skin area exposed to being only the forearms, instead of both trunk and arms, yields the following results (TABLE 4-7).

TABLE 4-7. Refined scenario dermal loads (L_{der}) and dermal doses (D_{der}) of TDI and MDI in the respective samples with findings. Input parameters for the calculations are also given. The skin area is only that of the forearms given in TABLE 4-5.

Substance	Sample	Skin area (cm^2)	BW	Migr / 12 h [mg/cm^2]	L_{der} [mg/cm^2]	$D_{der, external}$ [mg/kg bw/d]
TDI	O-10	330.9	15.6	1.1×10^{-4}	1.4×10^{-3}	0.029
MDI	O-10	330.9	15.6	1.5×10^{-6}	1.8×10^{-5}	0.00038
MDI	O-11	330.9	15.6	1.9×10^{-5}	2.3×10^{-4}	0.0049

4.3 Risk assessment

Due to the lack of appropriate hazard data, a quantitative risk assessment cannot be performed for neither TDI nor MDI.
Instead, a qualitative risk assessment in line with the ECHA guidance chapter R.8 and part E (ECHA, 2012; 2016b) is attempted here. The qualitative approach uses the health hazard classification and underlying data for categorisation of the substances in hazard bands of systemic and local effects: “high hazard”, “moderate hazard” and “low hazard” qualitative. For each hazard band, general risk management measures and operational conditions (RMMs and OCs) are suggested. As described in chapter 4.1 above, the most relevant hazards identified for the scope of this project are skin irritation, skin sensitisation as well as carcinogenicity.

Skin irritation
The simultaneous classification for irritant effects to skin, the eyes and respiratory tract (H315, H319 and H335), causes a categorisation of both substances in the moderate hazard band. (E.3.4.2 in ECHA, 2016b). However, no suggestions regarding RMMs or OCs applicable for consumer articles are derived from this categorisation.

An alternative strategy for qualitative assessment is considering the generic concentration limits of ingredients classified for skin irritant hazard that trigger classification of the mixture as irritating, following Table 3.2.3 in the CLP Regulation (1272/2008). For substances classified as Skin irritant Category 2, the highest concentration of this ingredient not generating classification of the mixture is 10 %. Considering the sweat simulant a mixture, the allowed concentration of a Skin Irrit Cat 2 substance in a non-irritating mixture is <10% (100,000 mg/kg). The analytical results of TDI in artificial sweat are well below this value.

It is noted, that for the classification of MDI, a substance specific concentration limit of ≥ 5% is defined. Applying this specific concentration limit and following the same argumentation as for TDI above, the allowed concentration of the MDI in the sweat simulant mixture is <5% (50,000 mg/kg). The analytical results of MDI in artificial sweat are well below this value.

In conclusion, skin irritating effects of TDI and MDI are unlikely to occur via exposure through textile articles made of recycled polyester based on their CLP classification and the threshold concentrations for classifying mixtures applicable for each of the substances.

Skin sensitisation
For substances classified as skin sensitisers (Category 1/1A/1B) according to CLP, studies should provide potency information, by which the substances can be categorised as an extreme, strong and moderate sensitiser (E.3.4.2 in ECHA, 2016b).

For MDI, the data available in the registrations dossiers are ambiguous and do not allow for final conclusions on potency, resulting in a harmonised classification as Skin. Sens. Category 1. In line with the precautionary principle, this causes the substance to be categorised in the "high" hazard band. For occupational exposure, certain RMMs or OCs applicable to high hazard band should be considered,[29] but for consumer exposure, RMMs or OCs are limited, and those available are not considering articles. A similar situation applies for TDI, having the same categorisation based on its harmonised classification.

Following the qualitative risk assessment methodology based on hazard bands, skin sensitizing effects of the substances cannot be excluded. Additional considerations therefore need to be applied for the risk assessment.

Carcinogenicity
For both TDI and MDI, the carcinogenicity data available in the registrations dossiers does not allow deriving any DNEL or DMEL values for the substances. Based on the harmonized carcinogenicity classification (Carc Cat 2, H 351) for both the substances, they are to be categorised in the "moderate" hazard band. For occupational exposure, certain RMMs or OCs applicable to moderate hazard band should be considered, following the ECHA guidance document, but no corresponding RMMs or OCs are applicable for consumers handling articles.

Following the qualitative risk assessment methodology based on hazard bands, the potential health risk effects related to the suspected carcinogenic properties of the substances can therefore not be excluded. Additional considerations therefore need to be applied for the risk assessment.

REACH Annex XVII concentration limit of 0.1%
For MDI, a concentration limit of 0.1% (1,000 mg/kg) by weight in mixtures intended for consumer use has been defined, even though background data for this concentration limit value is missing. A concentration limit for articles is not defined. The measured concentrations in both the GC-MS screening and the migration analysis suggest concentrations <0.1% (<1,000 mg/kg). Considering the sweat simulant a "mixture" or considering that the concentration limit could also apply for articles, it can be anticipated that the detected levels of the MDI do not pose a health risk. The same concentration limit for consumers was not developed for TDI. Even though a similar concentration limit of <0.1% for workers is in place since 2020, RAC has in the background document for the opinion on diisocyantes stipulated that it is assumed that these proposed measures will reduce the established risk of respiratory

[29] Examples of RMM and OC in the occupational environment are: High level of containment, closed systems, control staff for entry to work area, equipment maintenance, worker training, use of PPE. These RMM are not applicable to consumers.

sensitization as well as any other potential health risks, including any concerns about carcinogenicity (ECHA, 2018b). The fact that the measured residue levels of diisocyanate substances in textile from recycled plastics are well below the respective Annex XVII concentration limits indicate a low risk for hazardous effects from exposure to TDI and MDI via textile articles made of recycled polyester.

4.4 Discussion and conclusion on risk assessment

As the data is lacking on hazards derived from consumer use of diisocyanates-containing products, this impedes a quantitative risk assessment in this report. In cases where a quantitative risk assessment cannot be performed, the ECHA Risk Characterisation guidance (ECHA, 2016b) stipulates a qualitative approach. Qualitative risk assessments resulting in categorisation into hazard bands should be performed for skin irritation, skin sensitizing, and/or carcinogenic substances.

For skin irritation, the health risks are considered controlled for both TDI and MDI, following the different applicable concentration limits for the CLP classification of mixtures.

Sensitisation is *"essentially systemic in nature"* (ECHA, 2016b) and it may be that no lower threshold can be set for this endpoint, as is the case for respiratory sensitisation for workers (ECHA, 2018b). Both TDI and MDI therefore should be assigned to the high hazard band based on their skin sensitization classification, while for the carcinogenicity endpoint the medium hazard band is applicable. For these two hazard endpoints, it is difficult to conclude the risks are controlled for consumers being exposed via residue levels in textile, as no risk management measures and operational conditions are applicable for this type of use in any hazard band. However, it is noted that the analytically determined levels of MDI in the sweat simulant extraction from the textile samples are well below the concentration limit of 0.1%, which is defined as allowable content in mixtures in the restriction entry for MDI under REACH. TDI levels are also well below the concentration limit of 0.1%, even though a concentration limit is not defined for TDI in consumer articles but for industrial or professional uses only.

An alternative approach of assessing skin sensitising substances is the categorisation approach as outlined by Chilton et al. (2022). This approach is especially useful for substances without harmonised classifications and is used in other projects by the Danish EPA (Danish EPA, personal communication).

Chilton et al. (2022) categorises substances as high, medium and low potency skin sensitisers based on statistical analyses on the distribution of EC3 values from LLNA tests for a number of sensitising substances characterised as non-reactive (79 substances), reactive (331 substances) and highly reactive (146 substances). Chilton et al. (2022) then used the lowest 5% percentile of the EC3 values in the three groups as the Dermal Sensitisation Threshold (DST). For the non-reactive, reactive and highly reactive sensitisers, the DST values were set at 710 µg/cm^2, 73 µg/cm^2 and 1 µg/cm^2, respectively. Based on their harmonised classification as Skin Sens. 1, MDI and TDI can be regarded as moderate skin sensitisers, making the DST of 73 µg/cm^2 relevant for comparison with exposure estimates. Since the exposure estimates are well below 73 µg/cm^2 (highest dermal loads (L_{der}) for TDI is 1.4 µg/cm^2 and for MDI 0.23 µg/cm^2, see TABLE 4-6), this implies no risk for skin sensitisation.

It is noted that this interpretation is based on the harmonised classification as Skin Sens. 1. The classification as Skin Sens. 1 is applied where data are not sufficient for sub-categorisation into subcategory Skin Sens. 1A ("significant sensitisation in humans") or Skin Sens. 1B ("potential to produce sensitisation in humans").[30] The application of the DST approach does therefore not allow for unambiguous conclusions about the risk related to the

[30] Table 3.4.2 in CLP Regulation (1272/2008)

exposure of MDT and TDI but can be regarded as supporting information for concluding that the exposure to TDI and MDI from the textile products is unlikely to cause an unacceptable risk.

More detail and application about the DST-approach can be found in the original publication by Chilton et al. (2022), a review published by Bialas et al (2023) and the Danish EPA consumer project about plastic spectacles (Højriis et al., 2025).

The hazard and risk assessments of TDI and MDI are of limited elaboration due to lack of hazard data. The comparison of the exposure estimates with the REACH restriction concentration limit of 0.1% for MDI and the DST of 73 µg/cm^2 do not suggest unacceptable risks. However, the qualitative risk assessment cannot fully rule out whether the low levels of isocyanates that may be released from the textile articles made of recycled plastic can cause an unacceptable risk to children wearing such textiles. In any case, it is noted that there are no clear indications that diisocyanate substances are specific to recycled polyester, meaning that they could probably occur just as well in virgin textiles made of PET or PU.

5. Overall conclusion

The overall objective of the project is to build knowledge about the prevalence of consumer products containing recycled plastic, hereunder about the types (polymers) and origin of recycled plastic in consumer articles, which hazardous substances may occur in such articles, whether their occurrence is related to the recycling as well as whether those substances pose a risk to consumers, especially children, during the use phase.

The key findings of this study are:

Plastic polymers in consumer articles made of recycled plastic. PET, including polyester, is the most abundantly used recycled polymer (41%) in the toys, childcare articles, textiles for clothing, home textiles, and furniture, which were the consumer articles in focus in the survey about recycled plastics. The traceability of PET was highlighted as being higher than for other recycled polymers, being often collected separately, resulting in a more uniform and less contaminated recycled polymer fraction. Other recycled polymers are PE, PP, PS, ABS, nylon and – to a lesser degree – PVC. For around 31% of the articles in the survey, that were advertised as made of recycled plastic, the recycled polymer type was unknown.

Origin of the Recycled Plastics Used for Consumer Products. There is ambiguity and lack of information regarding the origin of recycled plastics in consumer articles. About half of the articles surveyed had an unspecified source of recycled plastic; approximately 40% were made from post-consumer recycled (PCR) plastics, and 10% from post-industrial recycled (PIR) plastics. The figures may be biased, as they are based on a relatively small number of consumer articles (62 articles) and on article descriptions from online retailers, who may have an interest in promoting their articles by claiming that they are made from PCR plastic.

Stakeholders emphasize that PIR plastic is easier to recycle due to its high purity and known composition. Estimates about volumes and distribution of PCR and PIR plastic could not be generated within the scope of this project. Overall, the data from the consumer article survey and the stakeholder consultation indicate that PCR plastic is more commonly used than PIR plastic in consumer articles (keeping the above-mentioned limitations about availability of information about origin and marketing bias in mind) with an expected increase of the volumes of PCR plastic.

Hazardous Substances in consumer articles made from recycled plastic. There are several reasons why hazardous substances can be present in consumer products made from recycled plastic. One reason is the presence of additives that were originally in the virgin plastic products. These additives, added for functional purposes such as durability, flexibility, colour, or present as impurities, remain in the recycled material. Another reason is the presence of legacy additives, which originate from the recycled plastic and were not intentionally added to the new recycled products. Additionally, the recycling process may involve the introduction of functional additives to enable the effective use of recycled plastic fractions such as heat stabilizers, odour maskers and/or pigments.

The literature review showed that numerous substances with hazardous properties can be present in consumer articles or recycled plastic material potentially used for consumer articles. Low levels of brominated flame retardants, organophosphate flame retardants, and some phthalates in consumer articles indicate that the substances' presence likely stems from the use of recycled materials or cross-contamination during recycling.

Many of the identified substances appear as legacy additives, which use in consumer articles is regulated and/or restricted via the REACH Regulation, POP Regulation, RoHS Directive and/or the Toys Directive, e.g., brominated flame retardants as PBDE, some phthalates, metals, eight PAH as well as some azodyes and the aromatic amine resulting from them. Other substances are only partly or not regulated in consumer articles via European regulations, e.g., novel flame retardants (such as TBBPA and its derivatives, brominated diphenyl ethyls and brominated phthalates), non-halogenated organophosphorus flame retardants, benzotriazole UV-stabilisers (except UV-328) and benzophenone-related UV-stabilisers.

Traceability and information transfer through the supply chain
The supply chain of recycled plastic articles on the Danish/European market involves numerous actors, who may be located both within and outside of Europe. The source and type of the recycled plastic is not always known in all parts of the supply chain.

The process from virgin plastic production to final consumer products includes steps where safety information, such as the Safety Data Sheet (SDS), may no longer apply or be accessible, particularly when the plastic is no longer in pellet form but has been transformed into an article. Consequently, end-users are typically unaware of any hazardous substances present in the products they use, which complicates the recycling process when the used articles become post-consumer waste.

Knowledge about presence of chemicals in the plastic waste is generated during the recycling, re-compounding and manufacturing of recycled plastic articles steps. According to Waste Framework Directive (2008/98/EC), the analysis shall be performed by the actor who is obliged to ensure the end-of-waste criteria.

The methods and frequency of chemical analyses of the recycled batches are highly varying and depend on the recycled waste stream, the recycler’s practice, and the customers’ requirements. No standards exist for how often a batch of recycled plastic must be analysed for its content of hazardous chemicals, nor which chemicals should be investigated. Batch-specific declarations on, e.g., the content of metals, content of SVHC substances or CLP compliance, may be provided by recyclers or compounders on demand from manufacturers.

For the recycled plastic pellets, a safety data sheet is created and provided to the manufacturer of (recycled) plastic articles. The SDS informs the manufacturers that the plastic is made from recycled waste and must also include added hazardous additives and leftover hazardous substances from the first use if present above a certain concentration threshold.

Purchase of textile articles of recycled plastic and chemical analyses. In order to obtain data for the risk assessment, a specific article group was selected for further investigation via chemical analyses. The article group selected were textile articles of recycled polyester, which were marketed for children or where exposure of children was considered likely. 20 articles, comprising both home textiles, children’s outdoor clothing and children’s clothing with direct skin contact were purchased.

Firstly, the articles were screened by a non-target analysis for organic substances (GC-MS screening) and metals (ICP-MS screening).

The GC-MS screening identified a total of 194 substances of which about 60% could be identified with confidence. Based on the substance’s concentrations, their number of detections, their hazard properties and regulatory status under REACH, eight substances and nine articles were prioritised for further investigation via migration analysis.

The presence of three – 12 metals could be identified per article in the ICP-MS screening. Overall, the concentrations of the metals found in the screening analysis did not cause any immediate concern with the exception of measured levels of antimony. Antimony trioxide is a commonly used catalyst in the process of PET synthesis. Therefore, its presence in PET bottles may not be surprising, and its migration potential to bottled water or other food stuff has been subject to earlier investigations. However, the potential health risks related to the presence of antimony in recycled PET was not further investigated in the scope of this study.

Secondly, eight prioritised substances were included in migration analysis simulating exposure via sweat. Of these, only three substances were measured above the limit of detection in the sweat simulant at concentrations ≤ 100 mg/kg: 2,4-toluene diisocyanate (2,4-TDI), 2,6-toluene diisocyanate (2,6-TDI), and 4,4'-methylenediphenyl diisocyanate (MDI). These three substances belong to the chemical group of isocyanates that are usually associated with polyurethane (PUR), and not polyester articles. Their presence cannot be interpreted as being specific for textiles made of recycled polyester.

Risk assessment of substances identified in the textile articles made of recycled polyester.
Due to lack of applicable, quantitative hazard data for consumer use of diisocyanates-containing products, a quantitative risk assessment could not be performed. Thus, the risk assessment was conducted based on a qualitative approach for skin irritation, skin sensitizing, and/or carcinogenic substances.

For skin irritation, the health risks are considered controlled for both TDI and MDI, following the different applicable concentration limits for the CLP classification of mixtures.

Skin sensitizing and carcinogenic effects of the substances cannot be excluded, following the qualitative risk assessment methodology based on hazard bands as outlined in the ECHA Guidance. Additional considerations therefore need to be applied for the risk assessment.

The analytically determined levels of MDI in textile samples are well below the concentration limit of 0.1%, which is defined as the allowable content in the restriction entry for MDI under REACH. TDI levels are also well below the concentration limit of 0.1%, even though such a limit is not defined for TDI in consumer articles but for industrial or professional uses only. The hazard and risk assessments of TDI and MDI are of limited elaboration due to lack of hazard data, and the qualitative risk assessment cannot fully rule out whether the low levels of diisocyanates that may be released from the textile articles made of recycled plastic can cause an unacceptable risk to children wearing such textiles. In any case, it is noted that there are no clear indications that diisocyanate substances are specific to recycled polyester. These substances are usually associated with polyurethane (PUR), and not polyester, articles. However, diisocyanates may occur in virgin or recycled polyester due to their use in glues (used for fixation of different textile layers or decoration, their use in surface coatings of PET or their use as polymerisation additives in virgin or recycled PET. Their presence can therefore not be interpreted as being specific for textiles made of recycled polyester.

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Annex 1. Questionnaires for stakeholder consultation

Appendix 1.1 Questionnaire for recyclers, producers and/or compounders

No.	*Question*	*Answer*
Consumer articles and manufacturers made of recycled plastics		
1	Do you know any consumer articles or manufacturers of consumer articles within the listed product categories made of recycled plastic? If yes, please provide links to the manufacturers' websites or attach product information sheets.	
	• Childcare products	
	• Toys	
	• Textiles (clothing or home textiles)	
	• Furniture	
Types of recycled plastic		
2	Which types of recycled plastics are typically used in these articles (e.g., ABS, PE, PP, PS, PET, …)?	
Presence of potentially hazardous additives in plastic types		
3	Do you have any knowledge about intentionally used additives, that could be present in the recycled plastic types? If you have any documentation, please attach it to your answer.	*e.g., triphenyl phosphate (flame retardant) in PS*
4	Do you have any knowledge about (legacy) additives stemming from the original plastic, that could be present in recycled plastic types? If you have any documentation, please attach it to your answer.	*e.g., phthalates in HDPE*
Origin of recycled plastic		
5	What is the source of the recycled plastic used for the articles, e.g., PCR (post-consumer recycled plastic), PIR (post-industrial recycled plastic), used plastic fruit packaging, etc.?	
Quality of the recycled plastic and information through the supply chain		
7	Are there any industry standards or company-specific quality criteria regarding chemical composition of the recycled plastics?	
8	Are there differences in chemical quality requirements for different industries? Are certain plastic fractions sold to certain industries?	
9	Are chemical analyses performed on the recycled plastics materials? If yes, how often (e.g., routinely on each batch or sporadically)? If yes, which substances are analysed?	

	If yes, how often are analyses performed?	
10	How is information regarding chemical composition and content of potentially hazardous substances in the recycled plastic transferred along the supply chain?	
Additional information		
11	If you consider additional information relevant for this project, please insert here.	

Appendix 1.2 Questionnaire for manufacturers and retailers

No.	*Question*	*Answer*
Consumer articles made of recycled plastics		
1	Do you have any consumer articles within the listed product categories made of recycled plastic? If yes, please provide links to the manufacturers' websites or attach product information sheets.	
	• Childcare products	
	• Toys	
	• Textiles (clothing or home textiles)	
	• Furniture	
Types of recycled plastic		
2	Which types of recycled plastics are these articles made of (e.g. ABS, PE, PP, PS, PET, …)?	
	• Childcare products	
	• Toys	
	• Textiles (clothing or home textiles)	
	• Furniture	
Presence of potentially hazardous additives		
3	Do you have any knowledge about intentionally used additives, that could be present in the recycled plastic types?	
4	Do you have any knowledge about (legacy) additives stemming from the original plastic, that could be present in the plastic types?	
Origin of recycled plastic		
5	What is the source of the recycled plastic used for the articles, e.g. PCR (post-consumer recycled plastic), PIR (post-industrial recycled plastic), used plastic fruit packaging, etc.?	
Quality of the recycled plastic and information through the supply chain		
6	What are the quality criteria regarding chemical composition of the recycled plastics?	
7	Which information regarding chemical composition is required from the supplier of the recycled plastic/from the manufacturer of the article made of recycled plastic?	
Additional information		
8	If you consider additional information relevant for this project, please insert here.	

Appendix 1.3 Questionnaire for industry and manufacturer associations

No.	*Question*	*Answer*
Manufacturers of recycled plastics or of consumer goods made of recycled plastics		
1	Do any of your members produce recycled plastics for consumer articles? Do any of your members produce consumer articles made of recycled plastic within the listed product categories of recycled plastic? If yes, please provide links to their websites.	
	• Childcare products	
	• Toys	
	• Textiles (clothing or home textiles)	
	• Furniture	
Presence of potentially hazardous additives		
2	Do you have any knowledge about intentionally used additives, that could be present in the recycled plastic types? If you have any documentation, please attach it to your answer.	*e.g., triphenyl phosphate (flame retardant) in PS*
3	Do you have any knowledge about (legacy) additives stemming from the original plastic, that could be present in recycled plastic types? If you have any documentation, please attach it to your answer.	*e.g., phthalates in HDPE*
Origin of recycled plastic		
4	What is the source of the recycled plastic used for the articles, e.g., PCR (post-consumer recycled plastic), PIR (post-industrial recycled plastic), used plastic fruit packaging, etc.?	
5	Do you have knowledge about compounders/plastic producers supplying manufacturers of consumer goods with recycled plastic materials? If yes, please provide links/contact information to these suppliers.	
Quality of the recycled plastic and information through the supply chain		
6	Are there any industry standards or company-specific quality criteria regarding chemical composition of the recycled plastics?	
7	Are there differences in chemical quality requirements for different industries? Are certain plastic fractions sold to certain industries?	
8	Is routine analysis performed on the recycled plastics? If yes, which substances are analysed? If yes, how often are analyses performed?	
9	How is information regarding chemical composition of and content of potentially hazardous substances in the recycled plastic transferred along the supply chain?	

Additional information		
10	If you consider additional information relevant for this project, please insert here.	

Annex 2. Analytical methods and sample preparation

Determination of organic substances by GC-MS screening

Sample preparation

Samples were taken from two specimens of each article for true duplicate determinations (except for sample O-10 and S-20, for which specimens were taken from the same article). A subsample of 10 cm^2 in duplicate was taken from each article, and the size and weight of the samples were noted. The subsample was extracted with dichloromethane/acetone added with an internal standard using ultrasound followed by mechanical shaking on a shaker table for 12 hours.

Screening method

The extract from the textile samples was analysed by capillary gas chromatography combined with mass-selective detection (GC-MS). To evaluate the results, the chromatograms were analysed by a specialist using MassHunter software. The chromatograms of all samples were compared to blanks and internal standard samples. The semi-quantitative screening analysis quantitates the analytes relative to the added internal standards. Due to expected differences in response factor this type of quantification is subject to uncertainty. The uncertainty is not the same for the different analytes. The MS spectrum of all relevant detected analytes was compared to NIST 20 and Wiley Registry 12th edition mass spectral databases and manually interpreted.

Each reported component was given one of three identification levels:

- Category A: Confident and confirmed identification with NIST hit rate ≥80%. The substance is identified by name, CAS no. (or NIST no. if CAS no. is not available for the substance in the library). It is noted that also for category A substances, some uncertainty remains regarding the precise substance identification.
- Category B: Partial identification. The substance is identified by chemical class of the compound, a fragment of the substance or by a compound bound to the substance. In some cases (especially for larger molecules with complicated structures), a suitable name for a chemical class is not available. In such cases, a substance name is chosen as class name, and CAS or NIST no. is not provided.
- Category C: Unidentified substance.

Semi-quantitative determination of metals and other elements by ICP-MS

Sample preparation

0.2 g sample – accurately weighed – were by means of microwave induced heating prepared with concentrated nitric acid. The resulting solution was diluted to 50 ml with Milli-Q water. Duplicate preparation was carried out. Blanks were made correspondingly.

Semi-quantitative screening by ICP-MS

The content of metals was analysed on inductively coupled plasma mass spectroscopy with mass selective detection (ICP-MS). With this method, it is possible to screen for the content of 62 metals from mass 6 (lithium) to mass 238 (uranium). The following elements could not be quantified due to interference: bromine (Br), calcium (Ca), carbon (C), chlorine (Cl), fluorine (F), iodine (I), nitrogen (N), oxygen (O), phosphorous (P), sulphur (S), and silicon (Si). The method is semi-quantitative and subject to some uncertainty. When more precise quantification is needed, a quantitative ICP-MS analysis with a reference compound is recommended. Germanium (Ge), rhodium (Rh), and rhenium (Re) were used as internal standards.

The samples were analysed according to Danish Technological Institute's method UA-263 with a reported uncertainty of 20% – 70%. No reference method was applied.

Annex 3. Analytical results from the screening analyses

Concentrations in mg/kg

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Naphthalene, 1,2-dihydro-	447-53-0		A	5	-	-	-	6.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Naphthalene	91-20-3		A	5	-	-	-	8.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Ethanol, 2-phenoxy-	122-99-6		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.9	-	-	-
GC-MS screening	Triethylene glycol	112-27-6		A	5	-	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Quinoline	91-22-5		A	5	-	-	-	-	-	-	5.2	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1,2-Benzenedicarboxylic acid	88-99-3		A	5	-	-	-	-	-	-	-	59	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 4-methoxy-N-methyl-	5961-59-1		A	5	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzene, 1,3-diisocyanato-2-methyl-	91-08-7		A	5	-	-	-	-	-	-	-	-	-	120	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzene, 2,4-diisocyanato-1-methyl-	584-84-9		A	5	-	-	-	-	-	-	-	-	-	380	-	12	-	-	-	-	-	-	-	-
GC-MS screening	1H-Isoindole, 3-methoxy-4,7-dimethyl-	100813-60-3		A	5	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1-Dodecanol	112-53-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
GC-MS screening	3,6-Dimethylbenzene-1,2-diamine, N-methyl	-	499850	A	5	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2-Chloro-1,4-dinitrobenzene	619-16-9		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-
GC-MS screening	Tetraethylene glycol	112-60-7		A	5	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2-Naphthalenol	135-19-3		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	-	-	-	-
GC-MS screening	1-Dodecanamine, N,N-dimethyl-	112-18-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	6.7	-	-
GC-MS screening	Butylated Hydroxytoluene	128-37-0		A	5	-	-	-	-	-	32	-	-	-	-	-	-	-	3.1	-	-	-	-	17	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	1,6,11-Trioxacyclopentadecane	295-63-6		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.4	-
GC-MS screening	1,6-Dioxacyclododecane-7,12-dione	777-95-7		A	5	-	-	-	-	-	-	-	-	-	-	68	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 4-nitro-	100-01-6		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-
GC-MS screening	Diethyl Phthalate	84-66-2		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-
GC-MS screening	Dodecanoic acid	143-07-7		A	5	-	-	9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzoic acid, 2-(1-oxopropyl)-	2360-45-4		A	5	-	-	18	-	-	-	-	-	5.4	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 4-methoxy-2-nitro-	96-96-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	-	-	-	-
GC-MS screening	2-Ethylhexyl 2-ethylhexanoate	7425-14-1		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26
GC-MS screening	Ethylene glycol - Adipate - Diethylene glycol	-	446006	B	5	-	-	-	-	-	-	-	-	-	84	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1,4-Benzenedicarboxylic acid, monoethyl ester	713-57-5		A	5	-	-	18	-	-	-	-	-	7.2	-	-	-	-	3.2	-	-	-	-	-	-
GC-MS screening	Benzenamine, 2-chloro-4-nitro-	121-87-9		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45	-	-	-	-	-
GC-MS screening	3-Methylglutaconic acid, diethyl ester	-	223-06-1	C	5	-	-	-	-	-	-	-	-	-	530	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2,6-Dichloro-4-nitroaniline	99-30-9		A	5	-	-	-	-	16	-	-	46	-	-	-	-	-	3	14	-	-	-	-	-
GC-MS screening	Ethanol, 2-(dodecyloxy)-	4536-30-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
GC-MS screening	Benzyl Benzoate	120-51-4		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	310
GC-MS screening	1H-Benzimidazole, 5-nitro-	94-52-0		A	5	-	-	-	-	-	-	170	-	-	-	-	-	27	-	-	18	-	-	-	-
GC-MS screening	Pentaethylene glycol	4792-15-8		A	5	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 2-bromo-6-chloro-4-nitro-	99-29-6		A	5	-	-	-	-	-	-	-	-	7.4	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	N-Pyridin-3-yl-benzenesulfonamide	53472-19-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	13	-	14	25	-	-	-	-
GC-MS screening	1-Octadecene	112-88-9		A	5	-	-	-	-	-	-	-	-	-	-	140	-	120	-	-	-	72	-	-	-
GC-MS screening	2,4-Diphenyl-4-methyl-2(E)-pentene	22768-22-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	-
GC-MS screening	Unidentified adipate	-		B	5	-	-	-	-	-	-	-	-	-	290	-	-	-	-	-	-	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Unidentified adipate	-		B	5	-	-	-	-	-	-	-	-	-	320 / 43	-	-	-	-	-	-	-	-	-	-
GC-MS screening	dl-Isocitric acid lactone	4702-32-3		B	5	-	-	-	-	-	-	-	-	-	66	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Bis(2-hydroxyethyl) phthalate	84-73-1		B	5	-	-	-	-	-	-	-	43	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 2-chloro-4,6-dinitro-	3531-19-9		A	5	-	-	-	-	36	-	-	160	-	-	-	-	10	-	270	85	-	-	-	-
GC-MS screening	2-Propenamide, N-[2-[ethyl(3-methylphenyl)amino]ethyl]-	-	396398	A	5	-	-	-	-	-	-	35	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 2,4-dinitro-	97-02-9		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-
GC-MS screening	unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-
GC-MS screening	Benzenamine, 2,6-dibromo-4-nitro-	827-94-1		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	77	-	-	-	-
GC-MS screening	Dimethyl palmitamine	112-69-6		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1,3-Dioxolane, 2-(methoxymethyl)-2-phenyl-	-	156712	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	-	-	-
GC-MS screening	n-Hexadecanoic acid	57-10-3		A	5	-	-	17	-	-	-	-	-	8.8	-	-	-	-	-	-	-	-	-	6.3	12
GC-MS screening	Benzenamine, 2-bromo-4,6-dinitro-	1817-73-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	-	-	-
GC-MS screening	Diethylene glycol monododecyl ether	3055-93-4		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
GC-MS screening	1,6,11-Trioxacyclopentadecane	295-63-6		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9,3 / -	-
GC-MS screening	Methyl 1-amino-pentasulfide - 5-Sulfinate	-	2000321-65-1	B	5	-	-	-	-	-	-	8.3	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	N,N-diethyl-2-methyl-1H-benzo[d]imidazol-6-amine	-	2000171-60-5	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	-	-	-	-
GC-MS screening	Cyclohexadecane	295-65-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-
GC-MS screening	1-Octadecanol	112-92-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-
GC-MS screening	Hexadecane, 1-chloro-	4860-03-1		A	5	-	-	-	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	-
GC-MS screening	Cetene	629-73-2		A	5	-	-	8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzene, 1,1'-methylenebis[4-isocyanato-	101-68-8		A	5	-	-	-	-	-	-	-	-	-	56	450	-	-	-	-	-	-	-	11	-
GC-MS screening	9-Octadecenoic acid (Z)-, methyl ester	112-62-9		A	5	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Dimantine	124-28-7		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-
GC-MS screening	Ethylene glycol - Adipate - Diethylene glycol	-	446006	A	5	-	-	-	-	-	-	-	-	-	480	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1,4-Benzenediamine, N4-(2-aminoethyl)-N4-ethyl-2-methyl-	-	400284	B	5	-	-	-	-	-	-	360	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Phenol, 4,4'-(1-methylethylidene)bis-	80-05-7		A	5	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.6
GC-MS screening	Bis(2-ethylhexyl) maleate	142-16-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	-
GC-MS screening	Oxacyclohexadecan-2-one	106-02-5		A	5	-	-	-	-	-	-	-	-	-	-	-	7.3	-	6.3	-	-	-	-	-	-
GC-MS screening	1,4-Benzenedicarboxylic acid, bis(2-hydroxyethyl) ester	959-26-2		A	5	9.8	-	30	-	-	-	-	-	-	-	-	8	-	2.4	-	-	-	-	-	13
GC-MS screening	1-Decanamine, N-decyl-N-methyl-	7396-58-9		A	5	-	-	-	-	-	-	-	-	-	-	-	14	-	-	-	-	-	-	-	-
GC-MS screening	11-Octadecenoic acid, (Z)-	506-17-2		A	5	-	-	-	-	-	-	-	-	9.3	-	-	-	-	-	-	-	-	-	18	9.2
GC-MS screening	Palmitoleamide	106010-22-4		A	5	-	-	-	-	9.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	(2,5,7-Trimethyl-pyrazolo[1,5-a]pyrimidin-6-yl)-acetic acid ethyl ester	-	2000298-22-6	C	5	-	-	-	-	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-
GC-MS screening	Hexadecanamide	629-54-9		A	5	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Octadecanoic acid	57-11-4		A	5	-	-	-	-	-	-	-	-	5.8	-	-	-	-	-	-	-	-	-	10	-
GC-MS screening	Benzenesulfonamide, N-(3-hydroxyphenyl)-	59149-19-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	27	-	20	34	-	-	-	-
GC-MS screening	Hexadecanoic acid, butyl ester	111-06-8		A	5	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2-Butenedioic acid (E)-, bis(2-ethylhexyl) ester	141-02-6		A	5	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	15	-	210	-
GC-MS screening	Triethylene glycol monododecyl ether	3055-94-5		A	5	-	-	-	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-	-	10
GC-MS screening	hexadecyl acrylate	13402-02-3		A	5	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	12	-	-	-
GC-MS screening	Heptaethylene glycol	5617-32-3		A	5	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	9,12-Octadecadien-1-ol, (Z,Z)-	506-43-4		B	5	-	-	-	-	7.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Tricyclo[3.3.1.13,7]decane-1-acetonitrile, 2-phenyl-	117077-13-1		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	9-Octadecenamide, (Z)-	301-02-0		A	5	-	-	-	-	130	-	7.3	140	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Diethylene glycol - Adipate - Diethylene glycol	-	446007	A	5	-	-	-	-	-	-	-	-	-	120	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Octadecanamide	124-26-5		A	5	-	-	-	-	7.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	3-Hydroxyphthalic anhydride	37418-88-5		B	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	93	-	-	-
GC-MS screening	Octadecanoic acid, butyl ester	123-95-5		A	5	-	-	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Hexanedioic acid, bis(2-ethylhexyl) ester	103-23-1		A	5	-	-	-	-	-	-	-	-	-	-	84	-	-	-	-	-	-	-	-	-
GC-MS screening	Cyclohexane, 1,3,5-triphenyl-	28336-57-4		A	5	-	-	-	-	-	-	-	-	-	-	78	-	-	-	-	-	-	-	-	-
GC-MS screening	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]-	143-22-6		B	5	-	-	-	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Adipate Ethylene glycol	-	445975	B	5	-	-	-	-	-	-	-	-	-	370	-	-	-	-	-	-	-	-	-	-
GC-MS screening	9-Methyl-2,9-dihydropyridazino(3,4-b)indol-3-one	22294-02-6		B	5	-	-	-	-	-	-	9.4	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4		A	5	-	-	-	-	-	110	-	23	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1-tert-Butyl-1,1-dimethyl-N-(4-nitrobenzyl)silanamine	-	417406	B	5	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Bis(2-ethylhexyl) phthalate	117-81-7		A	5	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Octan-2-yl palmitate	55194-81-5		A	5	-	-	-	14	-	-	-	-	-	-	-	-	-	2.7	-	52	3 / 12	-	-	-
GC-MS screening	1,6,11,16,21-Pentaoxacyclopentacosane	56890-57-4		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	-	-	-	-
GC-MS screening	1H-Indole-1-acetic acid, 3-(ethoxycarbonyl)-5-hydroxy-2-methyl-, methyl ester	-	319070	B	5	-	-	-	-	-	-	-	-	-	-	-	-	16	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-
GC-MS screening	2-[2-[2-[2-[2-[2-(2-Hydroxyethoxy)ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethanol	5117-19-1		B	5	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-
GC-MS screening	Benzamide, 4-butyl-N-pentyl-	-	407450	C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.4	-
GC-MS screening	Hexadecanoic acid, decyl ester	42232-27-9		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47	-	-	-	-
GC-MS screening	2-[(2RS)-2-(2-Hydroxyethoxy)propyl]-2-methyl-1,3-dioxolane	102275-52-5		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9,2 / 51	-	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Benzoxazole, 2,2'-(1,2-ethenediyl)bis[5-methyl-	1041-00-5		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-
GC-MS screening	9-Octadecenoic acid, (E)-	112-79-8		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-
GC-MS screening	2-Ethylhexyl stearate	22047-49-0		A	5	-	-	-	13	-	-	-	-	-	-	-	-	-	9.2	-	40	12	-	-	-
GC-MS screening	1,4-Benzenedicarboxylic acid, 1,4-bis(2-ethylhexyl) ester	6422-86-2		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98 / 170	-	-
GC-MS screening	13-Docosenamide, (Z)-	112-84-5		A	5	-	-	12	-	-	260	-	-	-	-	-	2,3 / 11	3 / 9,6	13	-	-	-	-	15	8.4
GC-MS screening	Unidentified	-		C	5	-	-	-	-	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2,3-Dihydroquinoxalin-2,3-dione, 1-[2-acetoxyethyl]-6,7-dimethyl-	-	127855	B	5	-	-	-	-	-	-	-	120	-	-	-	-	-	-	230	-	-	-	-	-
GC-MS screening	Adipate Ethylene glycol	-	445975*	A	5	-	-	-	-	-	-	-	-	-	350	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Pentaethylene glycol monododecyl ether	3055-95-6		C	5	-	13	-	-	-	60	-	-	-	-	-	-	-	-	-	-	-	-	-	8.9
GC-MS screening	Hexaethylene glycol monododecyl ether	3055-96-7		B	5	-	-	8.7	-	-	19	-	-	-	-	-	-	-	-	-	-	-	-	-	8,4 / 4,8
GC-MS screening	1-Acetyl-2-amino-3-cyano-7-isopropyl-4-methylazulene	-	241324	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.4	-	-
GC-MS screening	Succinic acid, 2-octyl 2,2,3,3-tetrafluoropropyl ester	-	370973	C	5	-	-	-	-	-	-	-	-	-	-	170	-	-	-	-	-	-	-	-	-
GC-MS screening	12-Cyclohex-3-enyl-3-methyl-8,9,10,12-tetrahydro-7H-benzo[b][4,7]phenanthrolin-11-one	-	296085	B	5	-	-	-	-	-	-	-	-	-	-	130	-	-	-	-	-	-	-	-	-
GC-MS screening	Aristolactam II	-	2000346-10-4	C	5	-	-	-	-	-	-	-	-	-	83 / 49	-	-	-	-	-	-	-	7.7	-	-
GC-MS screening	2(3H)-Furanone, dihydro-5-tetradecyl-	502-26-1		A	5	-	-	-	-	-	-	-	-	19	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2-[2-[2-[2-[2-[2-[2-(2-Hydroxyethoxy)ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethanol	3386-18-3		A	5	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Stearic acid, isohexyl ester	-	438986	B	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	96	-	-	-	-
GC-MS screening	2-Methyl-5,6,7,8-tetrahydro[1]benzothieno[2,3-d]pyrimidin-4-ylamine, TMS derivative	-	479757	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	260	-	-
GC-MS screening	3,6,13,16-tetraoxatricyclo[16.2.2.2(8,11)]tetracosa-8,10,18,20,21,23-hexaene-2,7,12,17-tetrone	-	2000640-93-0	B	5	78	84	110	73	92	130	68	93	97	-	-	110	80	100	-	-	-	29	60	35
GC-MS screening	Unidentified adipate	-		C	5	-	-	-	-	-	-	-	-	-	-	250	-	-	-	-	-	-	-	-	-
GC-MS screening	2-(4-Acetylphenylamino)-1,4-naphthoquinone	88590-25-4		A	5	-	-	-	-	-	-	-	-	-	440	520	-	-	-	-	-	-	-	-	-
GC-MS screening	3,6,13,16-tetraoxatricyclo[16.2.2.2(8,11)]tetracosa-8,10,18,20,21,23-hexaene-2,7,12,17-tetrone	-	398770*	B	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12 / -	-	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Phosphonous acid, phenyl-, diethyl ester	1638-86-4		C	5	-	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	57	-	-	-	-	-	-	-	-	-
GC-MS screening	Hexadecanoic acid, dodecyl ester	42232-29-1		A	5	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	-	-	-	-	-
GC-MS screening	1,6,11,16,21,26-Hexaoxacyclotriacontane	64001-05-4		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90	-	-	-	-
GC-MS screening	Nonadecane	629-92-5		A	5	-	-	9.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Adipate Diethylene glycol cyclic dimer	-	445974	A	5	-	-	-	-	-	-	-	-	-	97	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Heptaethylene glycol monododecyl ether	3055-97-8		B	5	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Binaphthyl sulfone	32390-26-4		C	5	-	5.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Dodecyl nonyl ether	-	406375	B	5	-	-	-	-	-	-	-	-	-	-	-	8.4	-	-	-	-	-	-	-	-
GC-MS screening	1H-Indene-1,3(2H)-dione, 2-(3-hydroxy-2-quinolinyl)-	7576-65-0		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	49 / -	-	-
GC-MS screening	2-[2-[2-[2-[2-[2-[2-[2-(2-Hydroxyethoxy)ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethoxy]ethanol	5579-66-8		B	5	-	-	8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1H-Indene-1,3(2H)-dione, 2-(3-hydroxy-2-quinolinyl)-	-	2000422-07-1	A	5	-	-	-	-	-	-	-	-	-	-	140	-	-	-	-	-	-	-	-	-
GC-MS screening	3,6,13,16-tetraoxatricyclo[16.2.2.2(8,11)]tetracosa-8,10,18,20,21,23-hexaene-2,7,12,17-tetrone	-	398770*	A	5	23	4.9	13	5.4	-	22	-	-	-	-	-	-	-	3.3	-	-	-	-	10	7.5
GC-MS screening	Decyl oleate	3687-46-5		A	5	-	-	-	22	-	-	-	-	-	-	-	230	33	-	-	-	-	-	9.8	-
GC-MS screening	Octadecanoic acid, dodecyl ester	5303-25-3		B	5	-	-	-	-	-	-	-	-	-	-	-	6.7	-	-	-	-	-	-	-	-
GC-MS screening	1-Decanol, 2-hexyl-	2425-77-6		B	5	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-
GC-MS screening	3,6,13,16-tetraoxatricyclo[16.2.2.2(8,11)]tetracosa-8,10,18,20,21,23-hexaene-2,7,12,17-tetrone	-	398770*	B	5	-	-	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	trans-9-Octadecenoic acid, pentyl ester	-	405191	B	5	-	-	-	9.9	7.9	-	7	-	27	-	-	22	9.4	11	-	-	-	-	-	-
GC-MS screening	9,10-Anthracenedione, 1-amino-4-hydroxy-2-phenoxy-	17418-58-5		A	5	-	-	-	-	-	-	-	-	8.2	120	-	-	-	-	-	-	-	59	-	20
GC-MS screening	1-Hydroxy-4-(p-toluidino)anthraquinone	81-48-1		A	5	-	-	-	-	-	-	-	-	-	-	1600	-	-	-	-	-	-	-	-	-
GC-MS screening	1-(2-Cyanostyryl)-4-(4-cyanostyryl)benzene	13001-38-2*		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.9	43	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	290	-	-	-	-	-
GC-MS screening	Octaethylene glycol monododecyl ether	3055-98-9		B	5	-	3.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	26 / 53	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	2,2'-Dihydroxybenzophenone, bis(tert-butyldimethylsilyl) ether	-	462449	C	5	160	200	170	130	190	220	140	180	210	-	120	170	170	210	29 / 240	47	-	40	78	66
GC-MS screening	A-Homo-4-oxacholestane, 3,5-epoxy-6-iodo-3,4a,4a-trimethyl-, (3.alpha.,5.alpha.,6.beta.)-	72349-16-7		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.6
GC-MS screening	1-(2-Cyanostyryl)-4-(4-cyanostyryl)benzene	13001-38-2*		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	12	-
GC-MS screening	hexadecanamide, N-methyl-N-(1-oxohexadecyl)-	-	402932	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	1H-Thiopyrano[3,4-c]pyridine-5-carbonitrile, 3,4-dihydro-6-isopropylthio-8-morpholino-3,3-dimethyl-	-	2000603-16-0	C	5	-	-	-	-	-	-	-	-	-	-	170	-	-	-	-	-	-	-	-	-
GC-MS screening	1-(2-Cyanostyryl)-4-(4-cyanostyryl)benzene	13001-38-2*		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.3	-	-
GC-MS screening	Adipate Ethylene glycol	-	445975*	A	5	-	-	-	-	-	-	-	-	-	190	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, octadecyl ester	2082-79-3		A	5	-	-	-	-	-	-	-	-	-	-	63	-	-	-	-	-	-	-	-	-
GC-MS screening	4,11-bis(azanyl)-2-(3-methoxypropyl)naphtho[2,3-f]isoindole-1,3,5,10-tetrone	-	2000632-92-8	A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-
GC-MS screening	1-(2-Cyanostyryl)-4-(4-cyanostyryl)benzene	13001-38-2*		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	49	-	-	-	-	-	-	-	-
GC-MS screening	14H-Benzo[4,5]isoquino[2,1-a]perimidin-14-one	-	306341	A	5	-	-	-	-	-	160	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Dimethyldioctadecylammonium bromide	3700-67-2		A	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-
GC-MS screening	Propanenitrile, 3-[[2-(acetyloxy)ethyl][4-[(2,6-dichloro-4-nitrophenyl)azo]phenyl]amino]-	5261-31-4		C	5	53	-	-	-	310	-	-	1200	-	-	-	-	-	8.2	140 / -	-	-	-	-	-
GC-MS screening	Bis(1,3-dioxoindene-2-yl)(2-quinolinyl)methane	-	2000707-52-6	C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	8.5	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	6.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	3-(Benzylamino)-1-phenyl-7-(trifluoromethyl)[1,2,4]triazolo[4,3-a]pyrimidin-5(1H)-one	-	2000642-90-2	C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	120	-	-	-	-

Analysis	Component (GC-MS)/ Element (ICP-MS)	CAS no.	NIST no.	Category	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
GC-MS screening	Unidentified	-		C	5	-	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Adipate Diethylene glycol cyclic dimer	-	445974*	A	5	-	-	-	-	-	-	-	-	-	240	-	-	-	-	-	-	-	-	-	-
GC-MS screening	Unidentified	-		C	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200 / 670	-	-	-	-	-

Analysis	Element (ICP-MS)	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
ICP-MS screening	Lithium	1.25	-	-	-	-	-	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Beryllium	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Boron	37.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Sodium	12.5	62 / 88	297	95	40	210	180 / 240	32	51	20	106	86	42	34	83	320	61	390 / -	287	106	140
ICP-MS screening	Magnesium	12.5	36	-	40	-	-	1569	-	-	-	-	93	-	24	-	13	-	-	46 / 74	1007	-
ICP-MS screening	Aluminium	50	-	-	68 / 38	-	-	99	-	-	-	-	143	-	-	-	-	-	-	-	-	-
ICP-MS screening	Potassium	12.5	14	24	68	-	13	42	-	-	-	15	24	14	14	15	13	8,7 / 28	-	-	27 / 46	-
ICP-MS screening	Scandium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Titanium	1.25	2,0 / 20	760 / 78	330 / 120	140 / 200	99	140 / 13	360 / 23	359	550 / 82	565	683	68 / 150	782	550 / 180	27 / 42	840 / 170	4,1 / 20	310 / 590	615	68
ICP-MS screening	Vanadium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Chromium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Manganese	1.25	-	-	-	-	-	6.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Iron	6.25	52	-	26	-	-	53	6,3 / 9,5	-	-	10	10	-	-	-	8,2 / 6,1	-	-	-	-	12
ICP-MS screening	Cobalt	1.25	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Nickel	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Copper	1.25	-	-	12 / -	-	-	-	-	-	-	5,8 / 1,3	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Zinc	2.5	2.8	-	9,1 / 4,8	-	-	296	-	-	-	4,1 / 2,7	5.7	-	-	-	7,4 / -	-	6,2 / -	-	"-" / 5,9	250
ICP-MS screening	Gallium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Arsenic	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Selenium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Rubidium	6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Strontium	1.25	-	1.8	7.1	-	-	34	-	-	-	-	15	-	1.3	-	-	-	-	2.4	-	-

Analysis	Element (ICP-MS)	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
ICP-MS screening	Yttrium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Zirconium	1.25	-	-	-	-	-	-	-	-	-	1.7	3.9	-	-	-	-	-	-	2.4	1.3	-
ICP-MS screening	Niobium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	-
ICP-MS screening	Molybdenum	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Ruthenium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Palladium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Silver	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Cadmium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Indium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Tin	1.25	7.0	-	4.0	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-
ICP-MS screening	Antimony	1.25	224	146	197	186	174	62	151	150	106	106	144	134	109	202	111	73	120 / -	134	140	107
ICP-MS screening	Tellurium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Caesium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Barium	12.5	27	96	1183	-	-	-	-	28	-	-	1067	56	65	-	-	-	150 / -	99 / 67	59	-
ICP-MS screening	Lanthanum	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Cerium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Praseodymium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Neodymium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Samarium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Europium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Gadolinium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Terbium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Analysis	Element (ICP-MS)	LOD	Sample ID H-01	Sample ID H-02	Sample ID H-03	Sample ID H-04	Sample ID H-05	Sample ID H-06	Sample ID H-07	Sample ID O-08	Sample ID O-09	Sample ID O-10	Sample ID O-11	Sample ID O-12	Sample ID O-13	Sample ID S-14	Sample ID S-15	Sample ID S-16	Sample ID S-17	Sample ID S-18	Sample ID S-19	Sample ID S-20
ICP-MS screening	Dysprosium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Holmium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Erbium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Thulium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Ytterbium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Lutetium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Hafnium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Tantalum	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Tungsten	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Osmium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Iridium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Platinum	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Gold	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Mercury	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Thallium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Lead	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Bismuth	1.25	-	-	-	-	-	-	-	-	-	5.4	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Thorium	12.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ICP-MS screening	Uranium	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Survey of chemicals in consumer products of recycled plastic - A risk assessment of textiles made of recycled plastic for children

The overall objective of the project is to build knowledge about the prevalence of consumer products containing recycled plastic, hereunder about the types (polymers) and origin of recycled plastic in consumer articles, which hazardous substances may occur in such articles, and whether these substances pose a risk to consumers, especially children, during the use phase.

PET is the most abundantly used recycled polymer (41%) in the toys, childcare articles, textiles for clothing, home textiles, and furniture made of recycled plastics. About half of the articles surveyed had an unspecified source of recycled plastic; approximately 40% were made from post-consumer recycled (PCR) plastics, and 10% from post-industrial recycled (PIR) plastics. However, it is noted that these figures are presumably biased.

The findings of the literature review support that hazardous substances can be present in consumer products made from recycled plastic for several reasons, e.g. as additives originating from the virgin plastic products, as additives added to improve properties of the recycled plastic or as impurities from the recycling process. To obtain data for the risk assessment, the specific article group of textile products made of recycled polyester with exposure to children, was selected for further investigation by chemical analysis.

A non-target screening identified about 200 different organic substances and 12 metals in the textile articles. A subset of articles was analysed further by targeted migration-to-sweat simulation analyses. Diisocyanates (2,4-TDI, 2,6-TDI and MDI) were the only substances measured in concentrations above the detection limit.

Due to lack of applicable, quantitative hazard data for diisocyanates in consumer use, a quantitative risk assessment could not be performed. Thus, the risk assessment was conducted based on a qualitative approach for skin irritation, skin sensitizing, and/or carcinogenic substances. For skin irritation, the health risks are considered controlled. For skin-sensitizing and carcinogenic effects qualitative risk assessment cannot fully rule out whether the low levels of isocyanates potentially released from the textile articles can cause an unacceptable risk to children wearing such textiles. In any case, it is noted that there are no clear indications that the substances are specific to recycled polyester, meaning that they could probably occur just as well in virgin polymer textiles made of PET or PUR.

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