Office for Product Safety & Standards

The use of recycled materials in consumer products and potential chemical safety concerns

Scoping study

March 2023

This work was commissioned by the Office for Product Safety and Standards (OPSS) for completion by WRAP.

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Executive summary

This research project aims to identify and evaluate risks arising from the use of recycled materials in specific consumer products. It considers the evidence for these risks and the evidence gaps which need addressing. It briefly considers how these risks might be reduced and what further actions might be needed to overcome the issues identified. It also establishes how informed selected businesses are of the regulations and chemical thresholds for the use of recycled materials, the sources of support and guidance available to them and the impact this has on the decision to use or not use recycled materials. It was commissioned by the Office for Product Safety and Standards (OPSS) to promote transparency to consumers and provide regulators with greater insight into potential safety issues posed by the use of recycled materials in consumer products.

Context

The use of recycled materials in the manufacture of new products is essential in the achievement of a circular economy[1], retaining material value for as long as possible and fully exploiting the environmental and social benefits therein. Use of recycled materials in some products such as construction materials and packaging is well established and is further driven by the targets committed to in the UK Plastics Pact, and the UK government's proposed tax on plastic packaging containing less than 30% recycled content.

However, recycling may lead to the retention of some toxic chemicals from the original waste product and the introduction of these chemicals into the new product where recycled content has been used. Due to the lack of tracing and regulations around the use of recycled materials in products, and because regulation lags behind the use of novel chemicals, there is a possible risk that currently-restricted substances could be re-entering new products through the recycling of products made before those chemical restrictions were put in place.

The global trade in wastes has led to complex flows of materials and associated toxic chemicals. This has led to international efforts to manage these flows and reduce the risks associated, such as through International treaties including the Stockholm Convention on Persistent Organic Pollutants or through regulations such as European Union and UK REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). The issue has received growing attention internationally, with particular focus on plastics wastes. Recent amendments to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, an international treaty aimed at reducing transboundary movements of hazardous wastes, include restrictions to restrict dumping of wastes, "often on developing countries under the pretext of recycling" (Orellana, 2021). The UN Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes, Marcos Orellana, recently highlighted the risks of recycling plastic with toxic chemicals, which could "concentrate toxic additives in plastics, generating new hazardous products" (Orellana, 2021). This report examines the downstream of this material flow by

[1] This refers to an economy in which resources, rather than being used once and disposed of as waste, are circulated and re-used, keeping them in use for as long as possible. For more, see WRAP or Ellen MacArthur Foundation.

reviewing use of recycled materials in some consumer products and the extent of risks posed to consumers by them.

Following a recent review by the Environmental Audit Committee on the presence of toxic chemicals in everyday products (Environmental Audit Committee, 2019), recommendations were made to limit unnecessary and potentially toxic chemicals making their way into consumers' homes. This provides the backdrop for this research.

Aims and scope

The project set out to answer the following questions:

- What are the potential chemical safety concerns relating to the use of recycled materials when compared with virgin materials in consumer products and associated user exposure risks?
- What are manufacturer's responsibilities when using recycled materials in products?
- What is the application and extent of uses of recycled materials in consumer products?
- What are the differences in the chemical makeup of products originating from within the EU and those from outside the EU?

There is a wide range of possible products which fall under 'consumer goods' and many different chemicals, otherwise termed analytes, in those products which could have chemical safety concerns. As a result, a more limited scope was agreed to identify priority product groups and analytes. These are listed below:

- Childcare articles and children's equipment
- Clothing, textiles and fashion items
- Cosmetics
- Electrical appliances and equipment
- Toys
- Furniture
- Motor vehicles

These categories align to categories used in the European Union's (EU) Safety Gate reporting system. The priority groups of chemicals identified below are based on the 2019 Environmental Audit Committee report:

- Bisphenols
- Flame retardants
- Formaldehydes
- Parabens
- Perfluorinated chemicals
- Other persistent organic pollutants
- Phthalates
- Heavy metals

The research for this report was undertaken as a series of concurrent, distinct but related pieces of research. Firstly, a literature review of published studies on the concentration of select chemical groups in certain product groups is presented (section 2.1). Secondly, analysis of the European Union's Safety Gate product alert portal was undertaken, offering insight into common chemical safety concerns and the distribution of product safety alerts across country of manufacture, to determine if any patterns can be identified between products manufactured in different regions (section 2.3). Thirdly, engagement with industry stakeholders was undertaken through an internet survey (section 3.1), in-depth telephone interviews (section 3.2) and a workshop (4.0). These were designed to verify the results of the surveys, Safety Gate analysis and literature review, as well as gain understanding of business regulatory awareness and decision making. Each section is summarised below.

Literature Review

The review of published literature returned over 250 datapoints across 128 publications relating to chemical safety in consumer products of interest or recycling and its relation to chemical hazard. Despite identifying a wealth of possibly relevant literature, a central conclusion of this stage is the limited confidence with which conclusions are made. Due to research primarily offering a single snapshot of the supply chain, such as a consumer product, most 'evidence' of recycling-based contamination is based on speculation when an unexpected chemical is found at levels below those which would suggest functional addition to the product. Some authors explicitly suggest that this contaminant could be a result of recycling, but many do not, which leads to challenges in comprehensively searching for and classifying evidence.

The results from the review of published literature suggest that **where restricted chemicals are identified in consumer products, the main driver of this is purposeful addition of those chemicals for specific functions in the product**, such as flame retardancy, plasticity, anti-stain properties and so on. Where the chemicals of priority in this review were detected, whether in recycled content or not, in most cases it was a small number of products which exceeded regulatory limits.

Generally, **there is insufficient evidence to form robust conclusions regarding the presence of chemicals from use of recycled materials for most chemical and product groups**.

However, one area exists where there is clear evidence of recycling-based contamination of consumer products: the recycling of e-waste plastics into new goods. These waste electronic and electrical equipment (WEEE) plastics, typically black plastics, may contain restricted flame retardants and heavy metals often used in association with flame retardants and in electronic products, such as antimony and lead, which persistent in the recycling process.

The evidence gathered is sufficient to piece together this flow of materials and chemicals. Waste electronics, particularly older items and certain product groups such as cathode-ray tube screens and television casings are well documented as having high concentrations of flame retardants (particularly brominated flame retardants) and associated heavy metals, which were purposeful additions to the products, many of which may have been made before the Stockholm Convention prohibited the use of POP-BFRs above certain concentrations. Observations of the recycling process suggest that sorting is often inadequate for identifying and excluding these restricted plastics, something which is of particular concern in emerging economies where the informal recycling sector is particularly prominent, including countries such as China and India. As well as generating substantial e-waste domestically, these countries with informal recycling systems are often the destination of e-waste exports, both legal and illegal. They are also the origin of many cheaper manufactured goods.

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These recycled hazardous e-waste plastics are being used in new consumer products which are then imported to the UK, and elsewhere across the world. It appears in many cases that hazardous plastic may be blended with non-hazardous, and recycled with virgin material, leading to highly variable chemical concentration between and within batches of the same product or, perhaps even within pieces of the product itself. As a result, the variation in contaminant presence is documented as spanning orders of magnitude. Black plastic products appear to be of particular risk for this contamination, and much research has been identified relating to black plastics in toys, but the problem appears to persist across groups including electronics, clothing accessories and household items.

Only a small number of studies made an explicit connection between chemical presence and human health risks. The results were inconclusive: most products had concentrations below concentration limits, but a non-negligible number of products substantially exceeded those concentration limits. In regards to consumer safety, very few tests of daily exposure risk were conducted. Where tests did occur, it was often in regards to chemicals appearing in products as functional additives; the *additional* risk associated with recycling-based contamination is an evidence gap. The exception again relates to unexpected flame retardants and heavy metals in black plastic products including toys: whilst marked by heterogeneity, some parts substantially exceeded legal limits of brominated flame retardants and heavy metals. This, combined with the particular exposure routes of vulnerable consumers, notably children through extended dermal contact and possible mouthing of toys, suggests possibly heightened risk. However, **more evidence to bridge the gap between recycled chemical presence and human health is needed.**

The results are caveated by the potential for biases in the literature. The lack of evidence for recycling-based contamination in most product groups does not amount to evidence that there is not a risk. Unexpected chemical risks from recycling are, by definition, unexpected – so researchers in many cases may not have conducted the necessary tests. This may be influenced by positive results bias, where research is geared towards re-creating existing findings and reporting positive results, rather than exploring other possibilities: the large number of studies evaluating flame retardants in toys seems in part to be driven by testing and replicating the findings of a 2009 study (S.-J. Chen et al., 2009). There are other potential biases at play: the increasing importance of e-waste as a growing, globalised waste stream and the emotive nature of safety concerns in children's toys may encourage research into these topics ahead of others. Finally, methodological biases and the cost of testing may allow more products to be screened for flame retardants and heavy metals than for other chemicals, leading to more available studies examining these chemicals than others. **Therefore, whilst we can state with some confidence that there exists an undesirable circular economy of waste electronic plastics into new consumer goods including toys, we cannot state with confidence that there are *not* other chemical safety concerns associated with recycled content, only that the evidence at present is lacking.**

Safety Gate Analysis

As a second stage of the literature review, the European Union's Safety Gate product alert portal was analysed. Safety Gate is used by regulators to share information about dangerous non-food products and alert other member states about the presence of product risks on the market. Nearly 4,000 chemical safety alerts were identified. This data does not provide information on risks associated with use of recycled content, but rather offers an idea of the broader trends in these product groups, as well as offering an indication of the country-of-origin of products with identified safety concerns. The quantitative overview was aimed to complement the detailed samples identified in the literature review..

Toys and clothing and textile items accounted for more than 95% of total alerts (72% and 24% respectively). This may suggests that these groups present the greatest safety concern. However, it may also reflect the relative numbers of items on the market, or possible biases in enforcement, with certain product types such as toys being disproportionately targeted for testing. Despite these caveats, the particularly high share of alerts (72%) being in the toys category would suggest that there may be a risk of toxic chemical presence in toys.

Within these product categories, certain types of product stood out: dolls and non-figurine toys, made primarily of hard and soft plastics, made up 71% of all toys related alerts. Footwear and accessories accounted for 69% of clothing safety alerts.

Safety alerts were raised overwhelmingly for products originating outside the EU: more than 90% of both toy and clothing alerts originated in non-EU countries, with China being particularly important for toy manufacturing (88% of toys had China as origin country, see Table 30). This suggests that health risks lie disproportionately with products imported from outside the EU.

Of the analyte groups of focus, only four were documented as being present in the Safety Gate dataset: phthalates, heavy metals, flame retardants and formaldehyde, which were mentioned in 76%, 22%, 14% and 2% of alerts respectively. Other POPs, perfluorinated chemicals, parabens and bisphenols were not mentioned in any of the alerts identified.

Phthalates were found overwhelmingly in the toys category, with heavy metals identified across both toys and clothing alerts. When combined with information on the product group and origin, the data suggests that phthalates are being used purposefully but at scales in contravention of European content limits. This suggests that there may be particular issues related to the use of phthalates at high concentrations in Chinese manufactured toys. This conclusion is caveated by being a known issue which is readily testable, which may be disproportionately targeted by regulators, leading to more safety alerts.

Whilst the Safety Gate information does not offer evidence pertaining to the risks of recycling, it does suggest that toys and clothing are the product groups in which chemical safety alerts are more regularly identified. This is comparable to the findings of the literature review. Phthalates and heavy metals appear to be the analytes identified most regularly. As known endocrine disruptors, the presence of phthalates in materials for children, a vulnerable population group, may be of particular concern. Whilst flame retardants were identified, they were not the most commonly identified chemical group, unlike in the literature where recycling was more explicitly stated as the reason for chemical presence. There is no data to suggest that these alerts came from the use of recycled content rather than purposeful addition of chemicals. The data does, however, offer insight into regional differences: **overwhelmingly, the risks are associated with products imported from outside the UK and EU**.

On-line Surveys

Two surveys were carried out, with manufacturers and retailers and material reprocessors. Due to both the low number of respondents and then the high non-response rate on key questions about chemical safety and testing, unfortunately very limited meaningful conclusions can be drawn from the reprocessor survey.

Amongst manufacturers and retailers surveyed (n=?), some key conclusions centre around the high reported use of recycled content. The majority of respondents (79%) indicate that they do use recycled content, and the majority (76%) also indicate that they blend recycled content with virgin materials. The toy manufacturers made up the percentage that don't use recycled content. Recycled content use and blending is driven primarily by price and material quality, but the transparency and certification of recycled content was highlighted as an important factor in sourcing recycled content, including the guarantee that it adheres to regulatory requirements.

The reported awareness of regulatory limits was high (over 66% respondents stating awareness), with both manufacturers and retailers and reprocessors regularly citing REACH (European Union chemical regulations) chemical lists as the primary reference point. For manufacturers and retailers, the responses to the survey suggest a general expectation that chemical safety concerns should be dealt with upstream by suppliers and manufacturers, with certification of material testing being used to ensure regulatory compliance. There was a suggestion both that this is how manufacturers and retailers currently adhere to regulations, and that this was how it should be adhered to.

Confidence in current safety practices was a recurring theme: concerns about chemical safety were evenly split between those concerned and those not concerned, with those not concerned primarily citing confidence in the testing regimes, their suppliers and the certification currently undertaken. The reliability, reach and enforcement of regulations like REACH and standards including OEKO-TEX and EN 71-3 were recurring themes. There was some variation between product groups: in particular, toy manufacturers and retailers used the survey as an opportunity to express the difficulty of using recycled content: one suggested it is "simply impossible to control the chemical content tightly enough".

Overall, the surveys points towards an engagement both with the circular economy and chemical safety of products, and some confidence in precautions currently taken and the role of standards and regulations. The expectation is that those upstream, namely the supplier and manufacturer, have the responsibility of testing and certifying their materials, and that this is currently undertaken for a wide range of chemicals. These results must be caveated by the limited convenience sample: the type of manufacturers and retailers who are sufficiently engaged with WRAP may be more reputable, responsible businesses with a demonstrated interest in circular economy issues. It is unlikely to be representative of the wider industries, particularly the industries based far less in, or completely outside of, the UK. Therefore the results may bias towards showing a more positive image of manufacturer and retailer engagement than will be the case across the wider industries.

In-depth Interviews and Workshop

In-depth interviews were held from each of the priority product categories, electronics, toys and soft furnishings. The aim of the interviews was to explore in greater detail the understanding of risks and barriers associated with the use of recycled materials, awareness of chemical thresholds and how they would manage these issues in relation to the use of recycled materials. This section was primarily qualitative and was intended to include diversity of experience and opinion.

Following on from the in-depth interviews, selected businesses and trade organisations were invited to a workshop to review and sense check the findings from the previous phases.

The interviews and workshops confirmed what was reported in the online surveys. Traceability of materials was identified as a common concern across all groups interviewed. The groups interviewed highlighted different priority concerns related to use of recycled materials and chemical safety more generally. Whilst electronic and textile retailers and manufacturers were confident in the safety of materials used, toy retailers and manufacturers considered that hazardous content was a barrier to the use of recycled materials. Further research would be required to understand whether or not there is a significant difference between industry groups concerns.

Stakeholders emphasised the difference between domestic production and imports. They highlighted a divide between, to use their terms, ‘reputable’ and ‘disreputable’ industry[2], with the latter far more likely to contravene chemical safety regulations, both in terms of purposeful additives of toxic chemicals and less stringent safety requirements on the plastics used, which may lead to the use of recycled e-waste plastics in new products. Toy manufacturers have emphasised that they believe that recycled plastic suppliers, particularly those in emerging economies with large manufacturing bases cannot guarantee the origin, consistency, traceability or regulatory compliance of recycled material. For this reason both toy manufacturers interviewed stated they did not wish to compromise the safety and quality of their products through the introduction of recycled materials, although their opinions cannot necessarily be generalised to all ‘disreputable’ manufacturers..

Overall findings

Bringing these distinct stages of the project to a single point, a coherent narrative begins to emerge, one which goes some way to answering the research questions, though gaps remain.

Firstly, **chemical safety risks of products appears to be driven primarily by the purposeful addition of functional additives to products**. Any risks from recycling stem from these initial additions of chemicals to products for desired effects. Phthalates, flame retardants and heavy metals are the main additives of concern and are particularly prominent for their use in toys (phthalates), electronics and furniture (flame retardants and heavy metals) and clothes (heavy metals). If recycling-based risks exist, these stem from the initial purposeful addition.

Secondly, **there is a clear and well-documented undesirable circular economy of e-waste plastics occurring globally**. Waste electronics containing restricted chemicals, mainly flame retardants and heavy metals associated with them, should be sorted and disposed of. In many cases, this is not happening. This is documented in emerging economies, such as India and China, where waste is exported to and substantial informal recycling industries exist. These plastics are then re-entering the UK and being exported around the globe in a diverse range of cheap plastic products, likely those manufactured in those same countries. This is of particular concern in black plastic goods. This is a well-documented material flow, and e-waste

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[2] *These were the terms used by participants in the stakeholder workshop. They are understood to represent, broadly, ‘reputable’ manufacturers and retailers: those who sell branded products, are members of industry trade associations and other bodies and so on and ‘non-‘ or ‘disreputable’ ones which sell unbranded, cheap products often imported and direct-to-consumer.*

appears to be the central component to it. The limitations of the research into recycled content chemical risks means other risks cannot be ruled out; there is simply insufficient robust evidence. Similarly, a big data gap is the extent to which the importing of these contaminated products constitutes a safety risk for consumers. The substantial variation in chemical concentration which comes from mixing plastics – possibly unbeknown to the manufacturer – means that the risk profile could possibly vary both between and within batches of the same product. More work translating concentrations of chemicals into consumer safety risk is needed.

Thirdly, **there is substantial variation within industries determined by the country of origin of the product and the nature of the business**. The Safety Gate data clearly points to the disproportionate role of non-UK and EU countries as the source of chemically unsafe products. Stakeholders emphasised the differences between 'reputable' domestic industry and 'disreputable' industry, including those who sell direct-to-consumer from factories in countries like China. The recycling of restricted plastics into new products appears to be happening primarily in these countries, too. This nuance between product quality is one often missed in the existing research on the risk of recycled materials. It is, however, an important nuance, as it will greatly impact the extent to which regulatory actions taken in the UK can prevent undesirable import risks.

Areas for future research

Based on these report findings, some key themes were identified as data gaps which could be addressed through future research:

- The gap between chemical presence and human health risk remains a data gap to be addressed, in particular calculating the health risks associated with the use of products with recycled content. This is relevant both to products which fall below and exceed legal requirements: in both cases, if these chemicals are unexpected in these products, they amount to an additional exposure route not typically considered. Due to the substantial variation observed within products, understanding the best- and worst-case risks is desirable.
- Literature biases may have created data gaps which could be counteracted through future systematic research, including publication of negative results. Some particular data gaps have been identified, with little evidence identified for certain chemicals and product groups, such as other POPs or cosmetics packaging for example, but it is unclear whether this is driven by an absence of chemical contaminants or an absence of testing. Systematic tests which target these data gaps will help to justify targeting particular products or chemical groups. In particular, the reporting of negative results is crucial to understanding whether there is an absence of evidence or if there is unlikely to be a risk of contamination. Regulators and governmental research can play an important role in overcoming the biases identified here.
- Expanded scope of chemical groups beyond those considered here may be relevant. As a scoping study, this report was not intended to offer an exhaustive overview, instead looking at a defined list of products and analytes (see 1.3). It is possible that this initial list has overlooked other chemicals which could persist through recycling. A comprehensive study by the Danish EPA details a large number of hazardous substances in plastics, including estimation of consumer exposure risk and fate of substance by recycling, based on the types of plastics in which the compounds are used and their

characteristics under mechanical recycling (Hansen et al., 2014). Systematically reviewing this evidence to classify compounds based on their potential for exposure and persistence in recycling would help to prioritise chemicals of concern beyond the list considered here.

- This report focused on specific products to analyse risks to consumers. However, due to the findings pointing out the importance of particular flows of materials (such as WEEE plastics), focusing on the product rather than the materials may limit our understanding of recycling-based contamination, and lead some products to fall between the boundaries. Where clear pathways for contamination are identified, such as the recycling of e-waste, future research should be based on the material types which fall into this category, to help build evidence of the scale of recycling-based contamination. A product focus in this report means that some potential evidence of e-waste recycling in other household black plastics such as kitchen implements and stationary, for example, was not included in the main dataset (See, for example: Puype et al., 2015; Samsonek & Puype, 2013; Vojta et al., 2017). By focusing future research on material types, clearer evidence can be generated about where recycled materials are destined.
- At present, the evidence of contamination of product samples is disparate and spread across numerous academic and governmental studies, as identified through the literature review (see 2.1). The detail presented for results from each sample is highly variable. There is not, to our knowledge, a repository for such data to be captured and compared. This could be a fruitful avenue to pursue: a tool such as a collaborative database to allow for reporting of results would contribute to further understanding the scale of the problem. For example, given the evidence presented for e-waste recycling into plastic products, particularly black-plastic products, a mechanism for standardised reporting of samples examining possible recycled e-waste contamination of new products could be beneficial to facilitate easier comparisons of the types of materials, products, colours, presence of restricted chemicals etc. This was beyond the scope of this initial scoping study, but the evidence identified here could form a useful starting point.

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Background and aims

Context

The use of recycled materials in the manufacture of new products is essential in the achievement of a circular economy[3], retaining material value for as long as possible and fully exploiting the environmental and social benefits therein. Use of recycled materials in some products such as construction materials and packaging is well established and is further driven by the targets committed to in the UK Plastics Pact, and the UK government's proposed tax on plastic packaging containing less than 30% recycled content.

However, recycling may lead to the retention of some toxic chemicals from the original waste product and the introduction of these chemicals into the new product where recycled content has been used. Due to the lack of tracing and regulations around the use of recycled materials in products, and because regulation lags behind the use of novel chemicals, there is a possible risk that currently-restricted substances could be re-entering new products through the recycling of products made before those chemical restrictions were put in place.

The global trade in wastes has led to complex flows of materials and associated toxic chemicals. This has led to international efforts to manage these flows and reduce the risks associated, such as through International treaties including the Stockholm Convention on Persistent Organic Pollutants or through regulations such as European Union and UK REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). The issue has received growing attention internationally, with particular focus on plastics wastes. Recent amendments to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, an international treaty aimed at reducing transboundary movements of hazardous wastes, include restrictions to restrict dumping of wastes, "often on developing countries under the pretext of recycling" (Orellana, 2021). The UN Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes, Marcos Orellana, recently highlighted the risks of recycling plastic with toxic chemicals, which could "concentrate toxic additives in plastics, generating new hazardous products" (Orellana, 2021). This report examines the downstream of this material flow by reviewing use of recycled materials in some consumer products and the extent of risks posed to consumers by them.

Following a recent review by the Environmental Audit Committee on the presence of toxic chemicals in everyday products (Environmental Audit Committee, 2019), recommendations were made to limit unnecessary and potentially toxic chemicals making their way into consumers' homes. This provides the backdrop for this research.

Research Questions

Primary and secondary research questions were determined:

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[3] *This refers to an economy in which resources, rather than being used once and disposed of as waste, are circulated and re-used, keeping them in use for as long as possible. For more, see WRAP or Ellen MacArthur Foundation.*

Primary question:

- What are the potential physical and chemical safety concerns relating to the use of recycled materials when compared with virgin materials in consumer products and associated user exposure risks?

Secondary questions:

- What are manufacturer's responsibilities when using recycled materials in products?
- What is the application and extent of users of recycled materials in consumer products?
- What are the differences in the chemical makeup of products originating from within the European Union (EU) and those from outside the EU?

These questions were addressed through desk-based research, surveys and interviews of stakeholders and stakeholder workshops.

As the project progressed, increased focus was given towards the issue of chemical risk. This was due to the approach taken and the evidence identified, which pointed to more product-specific information being available for chemical risks. As a result of this change of focus, the primary question was not fully successfully addressed. This is explored more in section 6.0.

Scope

Due to the wide range of possible products which fall under 'consumer goods' and analytes which could have chemical safety concerns, a more limited scope was determined of priority product groups and analytes.

Product groups

The priority product categories identified were as follows:

- Childcare articles and children's equipment
- Clothing, textiles and fashion items
- Cosmetics
- Electrical appliances and equipment
- Toys
- Furniture
- Motor vehicles[4]

These categories align to categories used in the European Union's (EU) Safety Gate reporting system.[5] Note that we have included the category 'Communication and media equipment' within the category 'Electrical appliances and equipment'. Whilst initially conceptualised as different categories, analysis of the data on Safety Gate (see section 2.3) found confusion amongst reporting Member States as to what constitutes each group, as certain items (notably headsets/headphones) were present in both. Both categories included reports for small, handheld consumer electronic devices with a difference not clearly defined. As a result, we considered it practical to group all electronic products in a single category, both under the

[4] *Whilst motor vehicles lie out of OPSS's remit, they were included in this study due to the large known chemical presence and common recycling of waste motor vehicle parts: if recycled into new consumer goods, they could impact the supply chain of other products within the OPSS remit.*

5 https://ec.europa.eu/safety-gate/

'Electrical appliances and equipment' title. Throughout, references to electricals are references to this combined group. Soft furnishings, such as carpets, rugs and upholstery have been included in the furniture group, in line with the groupings made by authors. Home textiles such as bed linen and towels have been included in the clothing, textiles and fashion items group.

Chemical groups

The priority groups of chemicals were identified based on a 2019 Environmental Audit Committee report, which in turn cites the Project NonHazCity (Environmental Audit Committee, 2019, p. 8):

- Bisphenols
- Flame retardants
- Formaldehydes
- Parabens
- Perfluorinated chemicals
- Other persistent organic pollutants
- Phthalates
- Heavy metals

Due to the regularity in which they were considered in the academic literature on toxic contaminants in recycling, heavy metals were also considered.

Note that persistent organic pollutants (POPs) are both a distinct category and one present in other categories, most notably flame retardants and perfluorinated chemicals. To avoid confusion and double counting, we have defined the POPs of interest as 'Other POPs', with evidence of those substances in multiple groups being assigned to the chemical group or purpose first. For example, hexabromocyclododecane (HBCDD) is a POP and flame retardant, so studies or safety alerts which examine HBCDD content in products are classified as evidence of flame retardants. Pesticides and insecticides such as Aldrin, Toxaphene and Mirex would be classified in the 'other POPs' category. As a result, POPs are likely to be underrepresented in quantitative analyses in the scoping study. This is a regrettable limitation but was considered a practical workaround to avoid double counting substances which fell into two priority groups.

Method

The research for this report was undertaken in multiple concurrent stages, including a literature-based scoping study, surveys and interviews with industry and a workshop with stakeholders. Presented here is a short methodological description of each stage, with more detail being offered in the corresponding report sections.

Scoping study

The desk-based research for the scoping study involved three distinct research avenues. Firstly, a review was conducted of the academic literature relating to the evidence of recycling-based contamination of consumer products and their associated safety concerns. The methodology is detailed in section 2.1.3. Secondly, existing regulations and standards relating to the priority product groups, analytes and use of recycled materials were researched. This is summarised in section 2.2. Thirdly, the EU Safety Gate portal for product alerts was investigated to identify any trends in the products or chemicals most commonly raised in safety alerts. The methodology for this research is detailed in section 2.3.

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Survey and interviews

The preliminary findings of the scoping study were used to inform two stages of surveying stakeholders to understand how chemical and physical safety concerns were understood by businesses. Firstly, an online survey was disseminated to both material reprocessors and product manufacturers, and retailers, to understand how they approach chemical and physical risks, their approach to use of recycled content and supply chain traceability. It was recognised that obtaining a representative sample for the relevant industries would be difficult, so a convenience sample was taken through dissemination of the survey amongst contacts of both WRAP and BEIS. This is detailed in section 3.1. This was followed by in-depth telephone interviews with a smaller selection of survey respondents who volunteered to engage in exploring the issue in more depth. This is detailed in section 3.2. It was recognised that obtaining a representative sample for the relevant industries would be difficult, so a convenience sample was taken through dissemination of the survey amongst contacts of both WRAP and BEIS. Participation in the survey and follow-up interview was voluntary.

Stakeholder workshops

Following the scoping study and survey stages, an open call was put out to stakeholders for a workshop to discuss and sense check the findings from previous phases. Like the survey, this was disseminated through networks of WRAP and BEIS and attendance and level of participation was voluntary. Attendees were sought to verify the results of the survey and interviews and discuss actions that would: increase understanding of physical and chemical risks from recycled materials; minimise business risk in using recycled materials; improve management actions across the supply chain to reduce risk; assign responsibility for ensuring risks are understood and accounted for; and increasing the overall use of recycled materials whilst avoiding a trade off against risk. The findings of the workshop are detailed in section 4.0.

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Scoping Study

Prior to the survey and stakeholder workshops (see sections 3.0 and 4.0, respectively), a scoping study was undertaken to map out existing knowledge of product safety concerns, associations with use of recycled materials and relevant regulations and standards which drive product safety. These stages were primarily undertaken to answer the secondary research questions (see section 1.1) and in turn, inform the primary research question.

This section contains three distinct avenues of research: a literature review of academic publications relating to possible recycling-based contamination of consumer products, a summary of relevant regulations and standards for consumer goods and materials used therein, and a quantitative analysis of EU Safety Gate product safety alerts.

Literature Review

The first part involved a review of published literature relating to toxic chemicals in consumer products and the extent to which an association with recycled materials was found. A summary of the results is presented in the following section, 2.1.1, and product group summary tables are presented in 2.1.2.

The following sections present in more detail the methodology and its limitations (section 2.1.3). The results are presented in more detail in section 2.1.4, arranged by product group. These findings are descriptions of the trends identified or not identified, their relation to recycling, and evidence of consumer safety risks. Brief summaries of each paper referenced is available in the Technical Annex. As well as the analysis of products, the literature review includes a section on evidence relating to the recycling process directly and the persistence of toxic chemicals through recycling (see section 2.1.4.3). These findings are then discussed, including the limitations of this literature review, in section 2.1.5.

Summary results

The review of published literature returned over 250 datapoints across 128 publications relating to chemical safety in consumer products of interest, or recycling and its relation to chemical hazard. Despite identifying a wealth of possibly relevant literature, a key finding at this stage is the limited confidence with which conclusions are made. The research typically takes a snapshot at a certain point in the supply chain: either the product sent for recycling, the waste and recycling centre, or a final product which may or may not have recycled content in it. The opaque and global nature of the supply chains and flows of raw materials, product manufacturing, waste products and recycling processes mean that tracking a material through those stages is incredibly difficult. As a result, most ‘evidence’ of recycling-based contamination is based on speculation when an unexpected chemical is found at levels below those which would suggest functional addition to the product. Some authors explicitly suggest that this contaminant could be a result of recycling, but many do not, which leads to challenges in comprehensively searching for and classifying existing studies.

Broadly speaking, the results from the review of published literature suggest that where restricted chemicals are identified in consumer products, the main driver of this is purposeful addition of those chemicals for specific functions in the product, such as flame retardancy, plasticity, anti-stain properties and so on. Where the priority analytes were detected, whether in recycled content or not, in most cases it was a small number of products which exceeded regulatory limits. The particular trends of product types are discussed in section 2.1.4.

There was, however, one area where clear evidence of recycling-based contamination of consumer products exists. This relates to the recycling of plastics from e-waste, typically black plastics, which contain flame retardants and heavy metals often used in association with flame retardants and in electrical and electronic equipment (EEE) , such as antimony and lead.

The evidence gathered is sufficient to piece together this flow of materials and chemicals. Waste electrical and electronic equipment (WEEE), particularly older items and certain product groups such as cathode-ray tube (CRT) screens and television casings are well documented as having high concentrations of flame retardants (particularly brominated flame retardants) and associated heavy metals, which were purposeful additions to the products, many of which may have been made before the Stockholm Convention prohibited the use of POP-BFRs above certain concentrations. Observations of the recycling process suggest that sorting is often inadequate for identifying and excluding these restricted plastics, something which is of particular concern in emerging economies where the informal recycling sector is particularly prominent, including countries such as China and India. As well as generating substantial e-waste domestically, these countries with informal recycling systems are often the destination of e-waste exports, both legal and illegal. They are also the origin of many cheaper manufactured goods.

These recycled hazardous e-waste plastics are being used in new consumer products which are then imported to the UK. It appears that in many cases hazardous plastic is blended with non-hazardous, and recycled with virgin material, leading to heterogeneity of chemical concentration between and within batches of the same product or, perhaps even within pieces of the product itself. As a result, the variation in contaminant presence is documented as spanning orders of magnitude. Black plastic products appear to be of particular risk for this contamination, and much research has been identified relating to black plastics in toys, but the problem appears to persist across groups including electronics, clothing accessories and household items.

Only a small number of studies made an explicit connection between chemical presence and human health risks. The results were inconclusive: most products had concentrations below legal limits, but a non-negligible number of products substantially exceeded legal limits. Very few tests of daily exposure risk were conducted. Where tests did occur it was often in regards to chemicals appearing in products as functional additives; the *additional* risk associated with recycling-based contamination is an evidence gap. The exception again relates to unexpected flame retardants in heavy metals in black plastic products including toys: whilst marked by substantial variation between and within samples, some parts substantially exceeded legal limits of brominated flame retardants and heavy metals. This, combined with the particular exposure routes of children through extended dermal contact and possible mouthing of toys, suggests possibly heightened risk. However, more evidence to bridge the gap between recycled chemical presence and the risk to human health is needed.

The results are caveated by the potential for biases in the literature. The lack of evidence for recycling-based contamination in most product groups does not amount to evidence that there is not a risk. Unexpected chemical risks from recycling are, by definition, unexpected – so researchers in many cases may not have conducted the necessary tests. This may be influenced by positive results bias, where research is geared towards re-creating existing findings and reporting positive results, rather than exploring other possibilities. There are other potential biases at play: the political importance of e-waste as a growing, globalised waste stream and the emotive nature of safety concerns in children's toys may encourage research into these topics ahead of others. Finally, methodological biases and the cost of testing may allow more products to be screened for flame retardants and heavy metals than for other chemicals, leading to disproportionately more studies examining these chemicals. Therefore, whilst we can state with some confidence that there exists an undesirable circular economy of waste electronic plastics into new consumer goods including toys, we cannot state with confidence that there are *not* other chemical safety concerns associated with recycled content, only that the evidence at present is lacking.

Summary tables

The evidence per product group is detailed in a summary table. These tables break the evidence into three stages which relate to the research questions:

- The extent of evidence of the analyte's presence in the product group;
- The extent of evidence that its presence is related to the use of recycled materials;
- The extent of evidence that recycled content may have implications for consumer safety.

1.1.1.1 Summary tables scale

The terminology relating to evidence of an analyte's presence and its connection to recycling is consistent, whereby 'none identified' relate to where evidence was missing, 'limited' refers to one to two datapoints, 'some' refers to three to five datapoints, and 'substantial' refers to above five datapoints. For ease of reading, areas where no evidence was identified are greyed out.

1.1.1.2 **Childcare articles**

Table 1: Literature review summary table, childcare articles

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	Limited	None identified	None identified
Flame retardants	Substantial	Concentrations of BFRs after bans and below functional requirements suggest contamination; role of recycling unclear but possible	Inconclusive: risk analyses focus on organophspohate flame retardants, which are implied purposeful additives, rather than BFRs, which are an implied contamination risk only in worst-case scenarios
Formaldehydes	Some; primarily in furniture/mats	None identified	Risk in worst case scenarios, not related to recycling
Parabens	None identified	None identified	None identified
Perfluorinated chemicals	Very limited	None identified	None identified
Other Persistent organic pollutants	None identified	None identified	None identified
Phthalates	Substantial	Only in relation to playground equipment	Mixed: exceedances of regulatory limits identified but few migration tests
Heavy metals	Some; primarily lead	Speculation; more likely origin as purposeful additive	Some exceedances of safety limits, no migration tests identified
Other	Limited evidence relating to Azo Dyes and PAHs	PAHs in playground equipment the only suggestion	Inconclusive

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1.1.1.3 Clothing and textiles

Table 2: Literature review summary table, clothing and textiles

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	Limited; primarily in socks/tights	Limited speculation of the role of recycled plastic in polyester, but bisphenol content appears to be driven by spandex used in association rather than polyester itself	Exposure route identified; health implications not stated
Flame retardants	Substantial; specific fabrics unclear, primarily identified in accessories	Speculation on the role of e-waste recycling	Not analysed
Formaldehydes	Some; functional additive	None identified	None identified
Parabens	Limited; functional additive	None identified	None identified
Perfluorinated chemicals	Substantial; functional additive	Not known to be recycled	None identified
Other Persistent organic pollutants	None identified	None identified	None identified
Phthalates	Some	None identified	None identified
Heavy metals	Substantial	Limited evidence of Sb (antimony) associated with polyester in particular Most heavy metal usage as dye or functional additive	Limited evidence that Sb from polyester posing non-negligible risk
Other	Numerous other chemical additives identified	None identified	Inconclusive

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Cosmetics

Table 3: Literature review summary table, cosmetics

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	Limited	Very limited speculation on recycling as cause	None identified
Flame retardants	None identified	None identified	None identified
Formaldehydes	None identified	None identified	None identified
Parabens	Some	Purposeful additive in cosmetic product; limited evidence as possible source of future contamination through recycling packaging	None identified
Perfluorinated chemicals	None identified	None identified	None identified
Other Persistent organic pollutants	None identified	None identified	None identified
Phthalates	Some	Purposeful additive in cosmetic product; limited evidence as possible source of future contamination through recycling packaging	None identified
Heavy metals	Limited	None identified	None identified
Other	Numerous other VOCs and SVOCs identified	Purposeful additive in cosmetic product; limited evidence as possible source of future contamination through recycling packaging	None identified

*Searches focused on cosmetic packaging, as the route by which recycling-based contamination judged most likely to occur. Evidence may not present full picture for cosmetic products.

1.1.1.4 Electrical appliances and equipment

Table 4: Literature review summary table, electrical appliances and equipment

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	None identified	None identified	None identified
Flame retardants	Substantial; CRT screens and TV casings particular concern	Substantial evidence of purposeful addition of FRs Purposefully-added FRs then expected to persist in plastics if recycled Some evidence suggesting recycled plastic a source of chemicals in EEE	Occupational risks for recyclers In EEE products, there are known risks which vary based on product, age, type of flame retardant Unclear if recycling-based contamination contributes substantially to risk
Formaldehydes	None identified	None identified	None identified
Parabens	None identified	None identified	None identified
Perfluorinated chemicals	Some; in circuit boards and EEE plastic	Limited; in one study, concentrations at rates which suggest presence "not caused by intentional addition"	None identified
Other Persistent organic pollutants	None identified	None identified	None identified
Phthalates	Limited	Detected in urine of those living near e-waste dismantling sites: unclear if persists in recycled product	Occupational risks for recyclers; unclear subsequent consumer risks in products
Heavy metals	Substantial; particularly Sb, Pb and Cd	Substantial evidence of purposeful addition, often in association with flame retardant But most heavy metals expected to persist in plastic if recycled	Occupational risks for recyclers Sb, Pb and Cd well documented in waste and possibly recycled electronics Unclear subsequent consumer risk in products
Other	None identified	None identified	None identified

*Evidence relating to occupational exposure in e-waste recycling sites was not our focus, so searches were not directed to finding these papers. With specific targeted research, there may be much more evidence than indicated here.

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1.1.1.5 **Toys**

Table 5: Literature review summary table, toys

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	Limited	None identified	None identified
Flame retardants	Substantial	Substantial evidence speculating the role of recycled WEEE in toys	Mixed: most instances fall below legal limits, but some parts substantially exceed them. Most migration tests judged to be within acceptable risk range, but maximum concentrations may present a human health risk.
Formaldehydes	None identified	None identified	None identified
Parabens	Limited; particular toy groups (slimy/liquid/paint)	None identified	None identified
Perfluorinated chemicals	None identified	None identified	None identified
Other Persistent organic pollutants	Limited; evidence of PBDD/Fs in association to PBDEs	Suggested origin in recycling of e-waste black plastic	Migration not studied, but measured levels exceeded proposed waste limits
Phthalates	Substantial	Substantial evidence of purposeful addition; limited speculation associated with recycled content	Some evidence of health risks, not necessarily tied to recycled content use.
Heavy metals	Substantial; in particular through association with flame retardants and as functional additive	Substantial evidence speculating the role of recycled WEEE in toys (primarily Sb) as well as functional addition	Mixed: most instances fall below legal limits, but some parts substantially exceed them.
Other	Formamide identified in one study	None identified	None identified

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1.1.1.6 Furniture

Table 6: Literature review summary table, furniture

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	None identified	None identified	None identified
Flame retardants	Substantial	Substantial evidence of purposeful addition; some evidence of low levels of restricted substances indicate recycling	Known risks, variation based on product, age, type of flame retardant
Formaldehydes	None identified	None identified	None identified
Parabens	None identified	None identified	None identified
Perfluorinated chemicals	Some	None identified	None identified
Other Persistent organic pollutants	Limited; chlorinated paraffins	None identified	None identified
Phthalates	Limited	None identified	None identified
Heavy metals	Limited	None identified	None identified
Other	None identified	None identified	None identified

1.1.1.7 Motor Vehicles

Table 7: Literature review summary table, motor vehicles

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	None identified	None identified	None identified
Flame retardants	Substantial	Substantial evidence of purposeful addition FRs in shredded plastic from ELV could be recycled into new products Some evidence of low FR levels in car plastic and textiles possibly due to recycling	Unclear: depends on new product ELV is turned into; no studies identified looked at exposure risk of FRs in indoor car environment
Formaldehydes	Limited	None identified	Unclear if safety concern; unclear if connected to recycling
Parabens	None identified	None identified	None identified
Perfluorinated chemicals	None identified	None identified	None identified
Other Persistent organic pollutants	None identified	None identified	None identified
Phthalates	Limited	None identified	None identified
Heavy metals	Limited	Limited speculation of heavy metal presence due to WEEE ELV plastics possibly recycle heavy metals into new products	Safety risks not analysed
Other	PAHs in tyres; numerous in indoor environment	PAH in tyres could be recycled	None, rubber granulate below safety limits

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1.1.1.8 Other; mixture of priority and non-priority groups

Table 8: Literature review summary table, mixed product groups

Analyte	Evidence of presence in product group	Evidence of connection to use of recycled materials	Evidence of consumer safety concern from recycled materials
Bisphenols	None identified	None identified	None identified
Flame retardants	Substantial	Substantial evidence of persistence in recycled plastic	Unclear: most evidence suggests contamination well below regulatory limits, lack of direct testing
Formaldehydes	Limited	None identified	None identified
Parabens	None identified	None identified	None identified
Perfluorinated chemicals	Limited	None identified	None identified
Other Persistent organic pollutants	Limited	Limited	None identified
Phthalates	Some	None identified	None identified
Heavy metals	Limited	Limited	None identified
Other	Limited: PAHs and rare earth elements	Limited: rare earth elements possibly associated with e-waste, inconclusive	None identified

Method

The literature review stage used a combination of methodologies to identify possible evidence on the scale of recycling-based contamination of consumer products. Our key focus was on papers which related to the chemical hazard of consumer products in the groups of interest (defined in section 1.3.2) with some evidence or speculation on the origin of those materials, and the relationship between those products and recycling (e.g. the product is believed to be made from recycled materials, or the product is expected to be recycled).

The approach taken combined three forms of evidence identification: searches using Science Direct and Google Scholar based on combinations of focus product and chemical groups; a 'snowball' approach looking backwards and forwards at highly relevant papers for the evidence they cited and the papers in which they were subsequently cited; and use of review articles which were broadly aligned with the research question. Both peer-reviewed, academic papers and 'grey literature' (such as government reports or publications by non-governmental organisations) were considered.

Based on these methods for finding evidence, potentially relevant publications were then evaluated based on the title, abstract and full text for evidence related to the research questions. Data were extracted from each study and grouped according to our product and chemical groups as best as possible. Due to inconsistencies between product categories used here and by authors, perfect matches were not always possible. This was collated in a spreadsheet format, with evidence split into datapoints based on the product and analyte groups of focus. For example, if a single study analysed the presence of BFRs in both toys and furniture, this paper would be divided into two datapoints, one for each product group. If a study were to analyse both BFRs and phthalates in both toys and furniture, this would lead to four datapoints, one for each product-analyte combination. Where used, *papers* refers to unique publications and *datapoints* to unique product-analyte combinations within papers.

The following sections refer to two datasets: the *full dataset* (FD), which includes all datapoints found through the search system described, regardless of whether the paper authors make any allusion to the role of recycling (either than a product will be recycled, or is made from recycled content). The *explicit recycling dataset* (ERD) is a subset of the FD which includes only datapoints where the authors speculated that the product had been recycled, or would be recycled. The need for this distinction is detailed more in section 2.1.3.2.

More detail on the methodology can be found in the Technical Annex.

1.1.1.9 **Dataset filtering**

The FD compiled evidence relevant to the investigation. This does not reflect every paper read or considered for inclusion but does reflect those which were considered and read in depth. As a result, it does not include evidence of products outside of our scope. Some of the excluded datapoints had conclusions or findings which were of possible relevance, such as about recycling more broadly or unspecific product groups. In some cases, these were analyses of non-focus product groups included in the same study as product groups of focus. A few notable datapoints are detailed in Table 9:

Table 9: Examples of out of scope but possibly relevant papers

Example papers	Product groups analysed	Chemical groups analysed
(Puype et al., 2015; Samsonek & Puype, 2013)	Black polymeric kitchen utensils	Flame retardants
(Straková et al., 2018)	Hair accessories / clips	Flame retardants
(Bečanová et al., 2016)	Mixed 'household plastics'	Perfluorinated chemicals
(Vojta et al., 2017)	Mixed 'household plastics'	Flame retardants
(Wassenaar et al., 2017)	Paper and paperboard consumer products	List of chemical groups, some in scope and some not
(ChemSec, 2019; Kazulytė, 2019; RIVM & Ramboll, 2019)	Food contact packaging	Phthalates; Flame Retardants

These are not intended to be representative of the scale of research in these product areas. Rather, they act as a signpost to areas which could be fruitful avenues for further investigation, should an expanded scope be considered appropriate. These excluded datapoints are not detailed in the results section, which is organised by product group. However, some of the findings of these papers, where relevant, have informed the conclusions described in the summary results (2.1.1).

Datapoints were coded based on their reference to recycling: those indicating that the product was made of recycled materials; that the product was likely to be recycled into new products; or without reference to recycling. The former two groups of datapoints were included in the ERD.

1.1.1.10 **Limitations**

The approach taken has some limitations. Firstly, the combined search method was not systematic in its approach, and some evidence may have been missed. Whilst attempts were made to reduce biases, some particular avenues, such as governmental sources, were not identified through this approach. However, in part thanks to review papers identified, most of the high-profile peer reviewed academic work in this space is likely to have been identified. The evidence presented here is not exhaustive, but can be considered comprehensive.

A Second limitation relates to how 'evidence' of recycling was identified. As identified throughout the literature review findings (section 2.1.1), actual *evidence* of recycling is scarce, and the papers cited mostly rely on speculation about recycling. To paraphrase, such speculation typically operates along the lines of: 'this chemical additive serves no purpose in the product, or is in the product at a scale below what would be required to serve a useful purpose, and therefore was likely not purposefully added to the product. We can theorise that its presence is a result of contamination during manufacturing, during transportation/end-of-life [for studies taking samples from waste and recycling centres], or as a direct result of recycled materials containing these additives being used in the manufacturing'. This created a complication for searches based on the recycling term: those papers which analyse similar products for similar analytes but do not speculate on the origin of the material were less likely to be identified. As a clear example, one Danish Environmental Protection Agency (EPA) paper identified levels of bromine small enough to imply non-purposeful addition, "even if there is no immediate other sources of content of bromine" (Andersen et al., 2014, p. 60). However, they do not examine the trace bromine further, nor do they speculate on how it might have got there, whether recycling-based impurity or not. The snowball methodology went some way to addressing this, provided the literature was identified by other authors, but it is likely that there is more literature available on consumer goods with no relation to recycling or material origins which we have not considered.

As a result of this second limitation, the main analysis focuses on the FD, which includes papers which make no reference to recycling, but do make reference to analyte groups and product groups of focus, as it was judged that the information contained therein would be of interest. However, because searches were not carried out for these products outside of the recycling-based searches and review articles discussed in section 2.1.3, it is likely in some cases that there is much more evidence relating to chemicals in consumer goods made from (believed) virgin materials. Given the number of product groups and analytes involved in this scoping study, a more systematic search of all evidence relating to toxic chemicals in consumer products regardless of origin falls beyond the scope and resource available.

Results

This section presents a summary of the results across all product groups, and within specific product groups. For each product group, the evidence relating to chemical presence, consumer safety and recycling-based contamination is summarised in a table. More detailed summaries of the papers considered can be found in the Technical Annex.

1.1.1.11 Heat matrix

The product-specific data is presented as a heat matrix to graphically represent datapoints and their distribution between product and analyte groups. This heat matrix represents the full dataset (FD) rather than the explicit recycling dataset (ERD), so includes both papers which explicitly referenced recycling and those which did not mention recycling.

The heat matrix also serves as a form of document navigation. The product group names link to the summary sections for those product groups, which are all in section 2.1.4.2. In the Technical Annex, the heat matrix is restated as a navigation tool whereby the values in the cells intersecting a product group and analyte group link to summaries of papers relevant to that product and analyte group.

As evident in the heat matrix visual representation (Table 10), most of the identified literature related to flame retardants, and the majority of this related to electrical appliances, with toys and furniture also having a large number of datapoints. Heavy metals is the second most referenced analyte group. Some chemical groups had very few identified datapoints: formaldehydes, parabens and other POPs (not including those POPs which fall into other categories, such as POP-BFRs).

Table 10: Full dataset evidence heat matrix

Product Group / Analyte Category	Bisphenols	Flame retardants	Formaldehydes	Parabens	Perfluorinated chemicals	Other Persistent organic pollutants	Phthalates	Heavy metals	Other
Childcare articles and children's equipment	2	6	3	0	1	0	7	3	2
Clothing, textiles and fashion items	2	7	3	1	7	0	5	14	4
Cosmetics	1	0	0	4	0	0	3	1	3
Electrical appliances and equipment	0	26	0	0	2	0	0	8	0
Toys	1	17	0	1	0	2	7	9	1
Furniture	0	16	0	0	5	1	1	2	0
Motor vehicles	0	8	1	0	0	0	2	2	2
Other; mixture of priority and non-priority categories	2	11	1	0	1	3	4	2	3

In addition to the product-by-product analysis, section 2.1.4.3 deals with observational evidence from the process of recycling, particularly WEEE recycling.

1.1.1.11.1 **Chemical Groups**

This section presents some descriptive statistics of the quantitative results regarding the priority chemical groups. The analysis was undertaken in two stages: firstly, based on FD which includes all papers relating to consumer products and recycling, but includes both those which mention recycling as a possible source of contamination and those which have no mention of recycling. Secondly, the ERD, a filtered sample which looks at only those which explicitly mention the possibility of recycling-based contamination having happened, or expected to happen, due to the presence of chemicals in consumer products. In both cases, those studies which were not explicitly about products but were about the recycling process (see section 2.1.4.3) are excluded. Due to limitations in the search process (see section 2.1.3.2) we expect the latter, filtered dataset (ERD) to cover more comprehensively the literature to which it applies; there are likely many more papers relating to consumer product safety independent of recycling which were not identified in this review.

For the product-specific FD, 111 papers were identified across which 220 datapoints relating to chemical presence were found. These are summarised by chemical group in Table 11:

Table 11: Papers and datapoints by chemical group, FD

Chemical Group	Number of papers identified*	Number of datapoints identified
Bisphenols	8	8
Flame retardants	58	91
Formaldehydes	9	8
Parabens	6	6
Perfluorinated chemicals	12	16
Other Persistent organic pollutants	5	6
Phthalates	25	29
Heavy metals	28	41
Other	14	15

**Note that the sum of papers by chemical groups will exceed the number of papers in the dataset, as some papers contained data on more than one chemical group so appear twice*.

The distribution of both papers and datapoints point to a particularly high interest in flame retardants, phthalates and heavy metals. This suggests that these substances are of particular concern in consumer products. Most notably this is due to the role of flame retardants and heavy metals in WEEE. These groups were often studied together: in fact, approximately 40% of the heavy metal papers and datapoints contained particular focus on antimony (Sb). This is due to the use of antimony trioxide as a flame retardant synergist in combination with halogenated materials. Thus, in many cases, whilst tests were conducted for heavy metals in products, this was done to test the possible presence of flame retardants in the material. As a result, the number of studies examining heavy metals has been inflated by the interest in flame retardants.

Secondly, considering the ERD, in which the authors explicitly mentioned the role of recycling as a possible source of contamination, a total of 112 datapoints across 52 papers were identified. Of these, nearly two-thirds of datapoints related to the suggestion that that recycling based contamination had already occurred in the product, as opposed to suggesting that contamination would occur due to the recycling of that product. The distribution of papers and datapoints is summarised in Table 12:

Table 12: Papers and datapoints by chemical group, ERD

Chemical Groups	Number of papers*	Number of datapoints
Bisphenols	4	4
Flame retardants	34	59
Formaldehydes	1	1
Parabens	1	1
Perfluorinated chemicals	3	4
Other Persistent organic pollutants	3	3
Phthalates	7	8
Heavy metals	13	25
Other	5	7

**Note that the sum of papers by chemical groups will exceed the number of papers in the dataset, as some papers contained data on more than one chemical group so appear twice*.

An interesting finding from Table 11 and Table 12 relates to the ratio of datapoints to papers for each chemical group; that is how many different product groups were studied within a single paper. What is notable is that for flame retardants and heavy metals, on average each paper examined two product groups of interest, whereas for formaldehydes, bisphenols and phthalates it was more common for one product group to be analysed in isolation. This could reflect that flame retardants and heavy metals were expected to be present in more product groups, so more product groups were studied. This could also reflect biases in study design based on the political importance of different chemical groups, particularly due to the growing importance of the waste electronic (WEEE) material stream. Alternatively, it may represent a sampling bias driven by accessibility: many of the papers studying flame retardants deployed a handheld x-ray fluorescence (XRF) analyser, within some cases screened sub-samples going for further in-depth laboratory analysis such as, for example, the use of a gas chromatography mass spectrometry (GC-MS) system. This may have allowed initial screening and investigation into certain chemicals to be more accessible and efficient, allowing for larger samples.

The datapoints coded in the ‘Other’ category related to those not clearly linked to a priority chemical group, or incorporating a priority group into a wider, non-disaggregated group. This included musks and siloxanes in cosmetics (Capela et al., 2016; Llompart, Celeiro, et al., 2013; Y. Lu et al., 2011), benzophenones in clothing (A. J. Li & Kannan, 2018; Xue et al., 2017), formamide in toys (Pettersson et al., 2018). Additionally coded ‘Other’, a number of papers looked at data relating to groups and lists of substances, such as rare earth elements (Turner et al., 2021), volatile organic compounds (VOCs) and SVOCs (Horodytska et al., 2020) or specific lists of chemicals of interest, such as the Dutch national list for substances of very high concern i.e. ZZS (Wassenaar et al., 2017) and the wealth of chemicals considered in a 2011 Finnish Environment Institute paper (Assmuth et al., 2011). Polycyclic aromatic hydrocarbons (PAHs) were discussed in papers relating to electronics and end of life vehicles, suggesting it could be an avenue for further investigation. (BfR, 2010; Bodar et al., 2018).

1.1.1.11.2 **Product Groups**

This section presents some descriptive statistics of the quantitative results regarding the priority product groups. The analysis is split into the FD and ERD. Due to limitations in the search process (see section 2.1.3.2) we expect the latter, filtered dataset (ERD) to cover more comprehensively the literature to which it applies; there are likely many more papers relating to consumer product safety independent of recycling which were not identified in this review.

Across the 111 papers, 220 datapoints related to specific products were identified. These are summarised by product group in Table 13:

Table 13: Papers and datapoints by product group, FD

Product Group	Number of papers*	Number of datapoints
Childcare articles and children's equipment	14	24
Clothing, textiles and fashion items	36	43
Cosmetics	10	12
Electrical appliances and equipment	32	36
Toys	27	38
Furniture	22	25
Motor vehicles	12	15
Other	18	27

**Note that the sum of papers by product groups will exceed the number of papers in the dataset, as some papers contained data on more than one chemical group so appear twice.*

Electrical appliances and equipment, clothes and textiles and toys are the three largest focus categories in terms of both datapoints and number of papers. Cosmetics and motor vehicles are the least studied groups. It is unclear whether this relates to distribution of risk or if the research interest is driven by other factors, such as the political importance of safety concerns in products for children, which may lead to toys and childcare articles having an increased amount of research being done.

When considering the ERD, which includes only papers where the authors make an explicit connection to recycling, a total of 52 papers documenting 112 datapoints were identified. These are distributed across the product groups as follows:

Table 14: Papers and datapoints by product group, ERD

Product group	Number of papers	Number of datapoints
Childcare articles and children's equipment	4	4
Clothing, textiles and fashion items	13	19
Cosmetics	2	4
Electrical appliances and equipment	24	29
Toys	17	22
Furniture	9	9
Motor vehicles	7	9
Other	10	16

**Note that the sum of papers by product groups will exceed the number of papers in the dataset, as some papers contained data on more than one chemical group so appear twice.*

Generally, the distribution of datapoints in the two samples is very comparable, the most notable changes being childcare as 11% of the total sample but just 4% of the sample where recycling is mentioned and electrical equipment increasing from 16% of the total sample to 26% of the recycling sample, suggesting it is a product group for which there is particular concern in recycling. The relationship between product groups, numbers of datapoints and shares of datapoints in the FD and ERD datasets is presented in Figure 1. For product groups where the dot is above the cross, such as electrical appliances, the product group is over-represented in the recycling-focused literature.

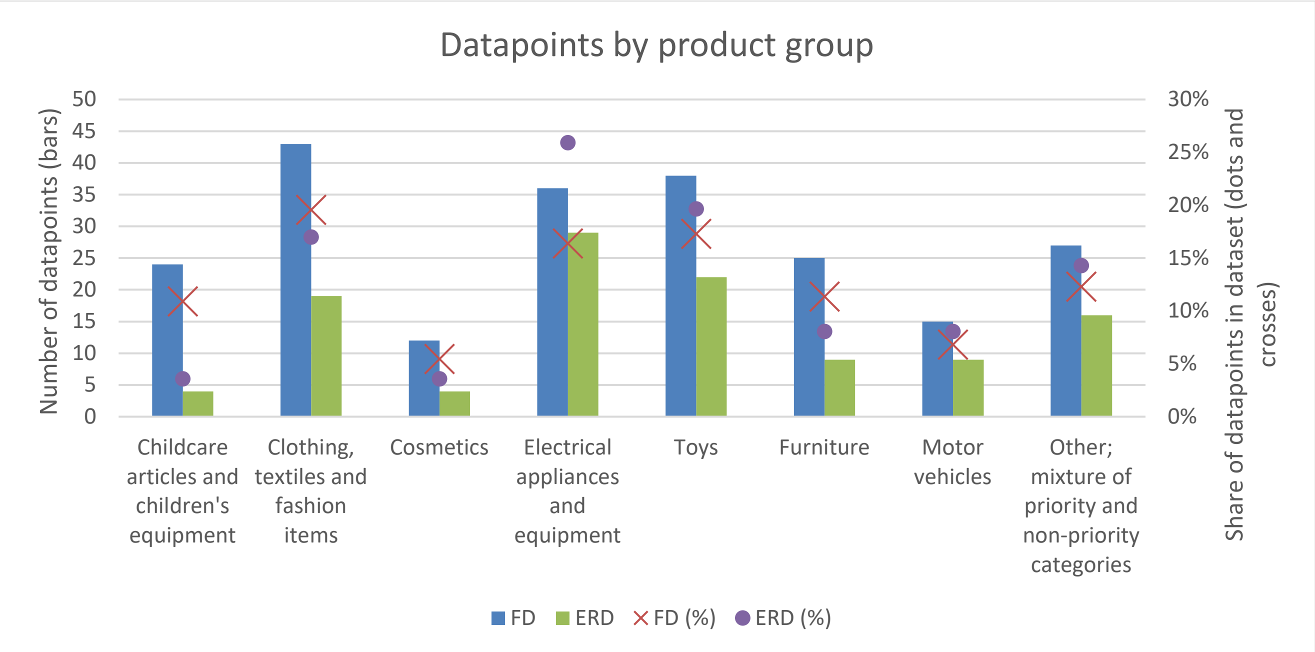

Figure 1: Distribution of datapoints by product group, FD and ERD. Where dots are above crosses, the product is over-represented in the literature which is explicitly about recycling.

The ‘other’ product category here generally refers to papers in which products were grouped including some priority products and some others, with data not presented in a disaggregated way. These includes grouped sampled of toys with packaging and general recycled plastics (Cook et al., 2020), waste household plastics (Pivnenko et al., 2016, 2017) and other general categories such as all not electronic items, or all items studied within a paper (Pettersson et al., 2018; Turner, 2018b; Turner & Filella, 2017b). In one experiment, the chemical content of consumer products can be inferred by an experiment relating to how their presence in dust changed with the replacing of old products in a preschool (Giovanoulis et al., 2019). Mixed products including toys, mats, furniture etc. which had in common that they were found in a preschool was also analysed in Pettersson et al. (2018). One group of products which fell out of the scope of the primary product groups here but were mentioned on a number of occasions was kitchen and office plastics, such as cooking implements, staplers and so on which are often made of black plastic, some of which is believed to come from recycled WEEE (Kuang et al., 2018; Leslie et al., 2016; Samsonek & Puype, 2013; Straková et al., 2018; Turner & Filella, 2017b). The regularity with which items such as kitchen implements were studied for WEEE-related chemicals, particularly flame retardants and heavy metals, and the findings being largely comparable to the findings for black plastic in toys (see 2.1.4.2.5) suggests they would be a product group worth further investigation.

1.1.1.12 **Results by product group**

The results are below presented by product group, summarising the key findings. For each product group, some descriptive statistics are followed by a summary of the scale of evidence, its relation to recycling and possible risks to human health. All data in tables refer to the FD, with the text describing those papers where recycling is explicitly mentioned. The evidence is presented in abridged form, more detail with a brief summary of each relevant paper can be found in the Technical Annex.

1.1.1.12.1 **Childcare articles and children’s equipment**

A total of 13 papers covering 24 datapoints were identified. The split of datapoints across analyte groups is summarised in Table 15:

Table 15: Distribution of FD datapoints, childcare articles

Analyte	Number of datapoints
Bisphenols	2
Flame retardants	6
Formaldehydes	3
Parabens	0
Perfluorinated chemicals	1
Other Persistent organic pollutants	0
Phthalates	7
Heavy metals	3
Other	2

This suggests that phthalates and flame retardants are the two chemical groups for which there is the most evidence in childcare articles, and that parabens and other persistent organic pollutants have not been the focus of research in childcare. The two 'other' pieces of evidence related to PAHs found in very low concentration and azo dyes exceeding REACH limits in some car safety seats, baby slings and baby mattresses (Mikkelsen, Brinch, et al., 2015) as well as analysis of the entire Dutch chemical concern list 'ZZS' in nappy waste (Wassenaar et al., 2017).

However, very few papers made even implicit references to recycling: some 83% of the childcare datapoints made no reference to recycling. The datapoints discussing bisphenols; formaldehydes and perfluorinated chemicals all had no reference to recycling, suggesting that within currently published literature, recycling is not a known route of contamination relating to those chemicals.

Bisphenols

Bisphenol A was found in the polycarbonate shield and ring of some 10-20% of baby dummies on the Danish market, but a migration test found no immediate health risks (Lassen et al., 2011). In Israel, 52 parts from childcare articles were tested for Bisphenol A, and it was found to exceed the EU directive (0.1 ppm) in 22% of baby textiles, 14% of baby mattresses, 45% of nappy-changing mats and 33% of feeding chairs sampled (Negev et al., 2018).

Flame retardants

Although only one paper on flame retardants made explicit reference to recycling, others referred to contamination based on existing of BFRs below concentrations suggesting functional usage. Even if not suggested by the authors, recycled content could be the source of these contaminants. Where bromine was detected at levels below capability of imparting flame retardancy included a nappy changing kit, bibs (both vinyl and non-vinyl) and a crib pad, hypothesised as being due to e-waste recycling (Miller et al., 2016). Similarly, an analysis of playmats in China identified ranges of flame retardants, both polybrominated biphenyl ethers (PBDEs) and Octylphenol ethoxylates (OPEs). They hypothesise that the variation does not originate from manufacturing, instead coming from the raw materials or additives used. They note that "all the samples analysed in the present study contained insufficient amounts of PBDEs to impart flame retardancy", indicating an origin such as contamination of the raw products (Peng et al., 2020). This does not necessarily mean recycled materials: the authors speculate that contamination during production, packaging, storage and transportation could be possible. A literature review conducted by Mikkelsen et al. (2015) identified BFRs in 2% of textile samples and 2.5% of textile pads (upper value of 500 mg/kg) in car safety seats for babies, levels which did not suggest intentional functionality. Organophosphate flame retardants were more common: Tris(1-chloro-2-propyl) phosphate (TCPP) in 35% of textile samples (up to 19,000 mg/kg), Tris(1,3-dichloro-2-propyl) phosphate (TDCPP) in 15% (up to 148,000 mg/kg), at levels which did suggest intentional functionality. They also found limited evidence of organophosphate flame retardants in baby slings and bromine in prams. Their original study of car safety seats, slings and mattresses found phosphorous-based flame retardants most regularly, with just two products including brominated flame retardants (BFR) at content up to about 1 mg/kg, suggesting "impurities in the materials" that "do not have a technical function in the final products" (Mikkelsen, Brinch, et al., 2015).

Other flame-retardant focused papers with no explicit mention of contamination included 36% of childcare samples having bromine detected in them and further tested for polybrominated biphenyl (PBB), PentaBDE and OctaBDE flame retardants, all of the results of which were negative (Negev et al., 2018). In the US, 79% of 101 sampled baby furniture items containing polyurethane foam (PUF) had an identifiable flame retardant additive, primarily TDCPP and the Firemaster500 mixture, although five samples had congeners associated with PentaBDE despite the phaseout a few years previously (Stapleton et al., 2011). A similar, more recent analysis of PUF containing mats for babies, children and adults in Denmark found no BFRs above the detection limit (2.4 mg/kg), indicating no violation of flame retardant content regulations (Poulsen, 2020). This could be indicative of changes over time leading to increased adherence to phase out of certain BFRs, or it could equally be driven by different markets having different flame retardancy requirements.

A small number of these papers discuss implications for safety: in the study of playmats, daily exposure for children was calculated. The combined risk exposure was some five to six orders of magnitude lower than reference dose values, suggesting "no obvious health concern regarding the occurrence of PBDEs and OPEs in play mats" (Peng et al., 2020). The US PUF furniture includes a proxy estimate of inhalation exposure of TDCPP, suggesting that infants may have greater exposure risk to TDCPP from child furniture than the average child or adult from upholstered furniture (Stapleton et al., 2011). Migration risk tests for phosphorus-based flame retardants in Danish car safety seats, baby slings and a baby mattress identified "an undesirable risk", but this was primarily in the conservative worst-case scenario. Note that this exposure risk is associated with the more abundant, purposefully-added phosphorus-based flame retardants and not the low-level contamination from BFRs, suggesting that risk was driven by purposeful additives rather than material contamination (Mikkelsen, Brinch, et al., 2015).

Formaldehydes

Formaldehydes were found in low concentrations across Danish car safety seats, slings and mattresses (Mikkelsen, Brinch, et al., 2015), but found in higher concentrations in baby furniture like feeding pillows and tumbling mats in Denmark (Poulsen, 2020; Tønning et al., 2008). One baby feeding pillow emitted formaldehyde which, in a worst case scenario, would contribute "significant part of the acceptable daily intake" (but not exceed it) (Tønning et al., 2008). In a worst-case scenario of a baby sleeping with three products just removed from packaging close to the zone of respiration, formaldehyde was identified to have unacceptable risk (Poulsen, 2020). For perfluorinated chemicals, Danish car seats were analysed but all fell below the detection limit. The literature review in the same paper indicated a previous finding in 33% of sampled pram textiles, up to 6 mg/kg 6:2 Fluorotelomer alcohol (FTOH) and 0.026 mg/kg perfluorooctanoic acid (PFOA).

Heavy metals

The heavy metal lead was discussed in a review paper of over 300 academic studies on consumer risk (D. Li & Suh, 2019). They identified seven reports about Lead in baby and child products through which dermal contact could be an exposure route. The authors mention that "recycling could also lead to occurrence of chemicals in recycled products" but in relation to products more generally rather than childcare specifically. In the case of Lead, it was expected to have been used as a colorant rather than originating from recycling-based contamination. Other studies examined heavy metals with no reference to recycling, including very limited evidence of lead in baby car safety seats (Mikkelsen, Brinch, et al., 2015) and trace metals in textiles, mattresses and nappy changing mats, with one mattress and two mats exceeding similar safety standards for antimony, lead and cadmium respectively (Negev et al., 2018).

Phthalates

One study of recycled rubber tyres in playground surfacing found high content of chemicals including phthalates and PAHs, the latter reached values up to 1% weight.

The authors conclude that the use of recycled tyres in playground areas and facilities for children should be a matter of regulatory concern (Llompart, Sanchez-Prado, et al., 2013). Phthalates were also mentioned in a number of papers with no discussion of recycling, including in the textiles of car safety seats, slings and prams with a small number exceeding regulatory standards (Mikkelsen, Brinch, et al., 2015); in a nursing pillow (Tønning et al., 2008), and miscellaneous childcare products (Poulsen, 2020; Strandesen et al., 2015), in all cases in a small number of samples and with limited instances exceeding regulatory standards. A study of phthalates in Japan included daily exposure estimates, but found that "the risk of exposure to phthalates from the diapers produced in Japan was negligible" (Ishii et al., 2015). In one study of non-polyvinyl chloride (PVC) mats for babies (mattresses, nappy changing, sheets etc.) in Israel, some 15% of samples exceeded the EU standard by mass for DEHP, with 7% above EU standard for DINP (Negev et al., 2018). Use of phthalates in non-PVC items is not regulated in Israel, and this may be the reason for the relatively higher detection. In some cases, the phthalate content was sufficiently low that that "the substances probably did not have an intended function", with the authors speculating the role of "impurities from other added components" (Mikkelsen, Brinch, et al., 2015; Poulsen, 2020). Feasibly, recycled content could be the source of such contamination, but this is not a suggestion the authors make and is not evidenced.

One study from the Netherlands looked at possible chemical risks in nappy waste, on the premise that as a substantial waste stream, circular economy solutions are being developed and it may therefore be a future source of recycled material. However, based on the data available, they found no issues with respect to content of their priority list of chemicals ('ZZS'), which included a number of the chemical groups considered here (Wassenaar et al., 2017).

All other studies identified contained no discussion of the role of recycling. As a result, discussion of consumer risk is expected to primarily relate to harmful additives in products.

A summary of these results can be found in Table 1.

1.1.1.12.2 Clothing, textiles and fashion items

A total of 43 datapoints across 35 papers were identified. The split of datapoints across analyte groups is summarised in Table 16:

Table 16: Distribution of FD datapoints, clothing and textiles

Analyte	Number of datapoints
Bisphenols	2
Flame retardants	7
Formaldehydes	3
Parabens	1
Perfluorinated chemicals	7
Other Persistent organic pollutants	0
Phthalates	5
Heavy metals	14
Other	4

This suggests that heavy metals are of primary concern in clothing, with evidence of perfluorinated chemicals, flame retardants and phthalates in a number of studies. No datapoints were found relating to other persistent organic pollutants. A recent review article by Rovira and Domingo (2019) offers an invaluable source of evidence on the association between textiles and chemicals including chemicals within the focus analyte groups and beyond it. What is notable from the review paper is that alongside the priority chemical groups in this paper, they also review papers related to nanoparticles, quinoline, benzothiazoles and benzotriazoles and aromatic amines. This would suggest that chemical safety concerns in consumer textiles extends beyond the priority analyte groups considered in this review. Indeed, through other searches, datapoints relating to benzophenones were identified in tights (A. J. Li & Kannan, 2018) and infant clothing (Xue et al., 2017) as well as lists of chemicals which far exceed the focus group here including dyestuffs, pigments, antioxidants and anti-mould agents in the Netherlands and Finland (Assmuth et al., 2011; Wassenaar et al., 2017).

None of the papers identified through the Rovira and Domingo review (2019) identified recycling as a possible source for the chemical content identified. In all cases, the origin of contamination was not discussed, it was expected as part of the raw material or processing and manufacturing, such as through dyeing (in the case of heavy metals) or adding textile qualities such as ‘crinkle-free’ fabrics (in the case of formaldehydes). As none of the papers relating to focus analytes identified through this review highlighted recycling as a contamination source, it is unlikely to be the case for the other chemicals discussed, with textile processing and manufacturing clearly a bigger driver of toxic chemical presence.

Of the datapoints, more than half (56%) involved no discussion of recycling. The datapoints relating to formaldehydes and parabens had no discussion of recycling, suggesting it is not a relevant route of contamination for those analytes.

Bisphenols

Two studies identified bisphenol content: one looked at Bisphenol A (BPA) and Bisphenol S (BPS) in infant clothing and found socks to be the item of clothing with highest BPA concentration (mean 1810 ng/g). This was particularly high in fabrics which were 97-98% polyester fabric (Xue et al., 2017). Similarly, BPA and BPS were found in 96% and 100% of tights samples (A. J. Li & Kannan, 2018). In both cases, estimates of dermal exposure were conducted: exposure for all analytes considered in the study were as high as 348 pg/kg-bw-day for full-length tights, of which bisphenols were the major share of exposure (A. J. Li & Kannan, 2018); and infant dermal exposure to bisphenols through textiles as high as 7280 pg/kg-bw/day in a worst case scenario.

In both cases, the authors highlight the role of the recycling of plastic bottles for the production of polyester and nylon yarn as a possible avenue for bisphenols in clothing. However, interestingly, BPA concentrations were much *lower* in 100% polyester infant clothing than in socks which were blended with 1-2% spandex and rubber. In both the cases of infant socks and tights, the authors identify that high BPA concentration in polyester fabric “is related to its combination with spandex” in socks and “the high percentage of Spandex in the garment” for tights (A. J. Li & Kannan, 2018; Xue et al., 2017). Whilst recycled materials are present, it may not be what is driving the chemical presence.

Flame retardants

Flame retardants have been identified in a number of clothing and textile items. Samples from the US testing for bromine found 70% of clothing to have Br; just under

60% of costume and accessories with Br and approximately 40% of footwear with Br. In most cases, these were under 100ppm, with some samples exceeding that (Miller et al., 2016, fig. 1). The same study also looked at jewellery and accessories (over 50% with Br) and plastic Mardi Gras beads, which were particularly notable as 90% had Br and 51% of samples had a concentration above 10,000 ppm. The authors suggest that e-waste recycling contributes to Br content, particularly in the plastic beads (Miller et al., 2016). Similar findings and conclusions were identified for other plastic fashion accessories including hair clips and headdresses. These results include samples from Czechia where OctaBDE and DecaBDE contamination was identified (Straková & Petrlík, 2017). Multiple studies across the UK found similar results, including: 54% of clothing items sampled having bromine detected in them (Turner, 2018b); 24% of clothing-upholstery samples (Turner & Filella, 2017a); 22% of clothing and accessories samples (Turner & Filella, 2017b). These studies only look at detection rates and concentrations rather than associated risk, but all speculate the role of e-waste recycling, particularly for plastic accessories such as jewellery, watch straps, wallets and so on. A non-recycling route was also identified based on PBDE levels in lint samples, where US PBDE levels from household dryer lint was some ten times higher than German dryer lint, the source of which “may be from dryer electrical components and/or dust deposition onto clothing” (Schecter et al., 2009). Of all harmful chemical substances identified as possibly present in textiles, based on human risk, a Dutch National Institute for Public Health and the Environment (RIVM) report prioritises chemicals: the flame retardant HBCD is considered one of the most relevant substances of concern, but they identify very little certainty on its presence in textile waste streams (Wassenaar et al., 2017).

Heavy metals

Heavy metals were widely documented. Of those which discussed the role of recycling, there was a focus primarily on antimony due to possible associations with flame retardants and e-waste: Sb regularly detected in samples in the UK in association with Br (Turner, 2018b; Turner & Filella, 2017a, 2017b) and found in the most abundance in items of polyester without detectable Br (Filella et al., 2020). Other heavy metals associated with recycling included Lead (Pb), detected in 29% of ‘clothing-accessories’ in one sample (Turner & Filella, 2017b) and 35% of clothing items in another, as well as Cr, Cadmium (Cd) and Mercury (Hg) detected in 21%, 8% and 6% of samples respectively (Turner, 2018b). Alongside these studies, heavy metals were regularly identified with no suggestion that recycling contributed to their presence: metals Copper (Cu), Cd, Zinc (Zn), Mn, Iron (Fe) and Nickel (Ni) being identified at higher levels from textile plants in Turkey than otherwise referenced in the literature, with Cu and Cd exceeding Oeko-Tex limit values (Tuzen et al., 2008); analyses of nearly thirty trace metals in a comparison of heavy metals in cotton, flax, hemp and wool fabrics (Rezic, 2011); those same trace metals in clothes articles (Rovira, 2015; Rovira et al., 2016) and ‘home textiles’ such as bedclothes and towels (Rovira et al., 2017); women’s underwear sampled in Texas (Nguyen, 2016); leather items in Denmark (Kolarik et al., 2019); and children’s jewellery sampled from Israel (Negev et al., 2018).

Some notable conclusions from these studies include higher levels of heavy metals in darker colour fabrics than lighter ones (Matoso, 2012; Nguyen, 2016); polyamide fabrics (regularly used for sports) high in Chromium (Cr) (Rovira, 2015; Rovira et al., 2017) and polyester regularly having high levels of Sb (Rovira, 2015; Rovira et al., 2016, 2017). The authors do not explicitly link this to recycled polyester, but it could act as an explanation. However, in the studies in which migration tests were carried out, it is clear that high concentration does not necessarily mean high risk: in nearly all cases, dermal contact risks were below Oeko-Tex Standard 100, although in some tests the Sb exposure from polyester was non-negligible, exceeding 10% of the safety limit and in one case exceeding hazard quotient (Rovira, 2015; Rovira et al., 2016, 2017) and the study of women's underwear suggested these exceed limits more regularly for Chromium (35% samples); lead (14% samples) and nickel (5% samples) (Nguyen, 2016).

Parabens

Parabens were examined in tights, with median concentrations up to 101 times higher in the samples purchased in China than elsewhere. The authors speculate that this was linked to high percentage of Spandex in the garment, and the possibility of parabens being used as an antimicrobial substance (A. J. Li & Kannan, 2018). Formaldehyde has also been widely tested for, including shirts, trousers and bed linen due to its use as an 'easy care', 'durable press' or 'wrinkle free' treatment. In some cases, these exceeded regulatory limits: a shirt and pair of trousers manufactured in China (Novick et al., 2013), ten items (6% of sample) from the US (USGAO, 2010) and for samples from the EU, 11% had formaldehyde above the Ecolabel voluntary limit of 30 ppm, with 3% exceeding the 75 ppm Oeko-Tex Standard 100 (Piccinini et al., 2007). None of these studies suggest that recycling plays a role in the presence of parabens or formaldehydes.

Perfluorinated chemicals

Perfluorinated chemicals are regularly used for coating garments; one estimate suggests that textile coating accounts for some 50% of global per- and polyfluoroalkyl substances (PFASs) use (Mikkelsen, Warming, et al., 2015), and they are widely used in rainwear, workwear, sleeping bags etc. However, it is not clear to what extent these are recycled: one study in Denmark, where PFASs-coated snow-wear is more prominent suggest "surface-treated fabrics are not suitable" for recycling, and are more likely to be exported abroad (Mikkelsen, Warming, et al., 2015). Another study suggests the recycling process of treated textiles had not been established, so "recycling is negligible" (Knepper et al., 2014). Bulk household textiles being exported make estimates on the amount possibly recycled very difficult (RIVM & Ramboll, 2019). Analysis in the Netherlands suggests some polytetrafluoroethylene (PTFE)-based workwear contains PFOA as an impurity (up to 5,000 ppm), often imported from outside the EU due to the European voluntary phase out of PFOA production (RIVM & Ramboll, 2019). It is unclear if recycling, or the lack of phase-out in other countries, would be the source of contamination. A number of other papers discussed the findings, often related to perfluorooctane sulfonate (PFOS) and PFOA, in textiles: in home and construction textiles in Czechia (Bečanová et al., 2016); in textiles in Thailand (Supreeyasunthorn et al., 2016); treated apparel in the US (Z. Guo et al., 2009); cotton and nylon in the US (Liu et al., 2014) and outdoor jackets in Germany (Knepper et al., 2014). Risk was only calculated in the case of Danish treated garments, but was considered low risk: PFAS exposure depends on its route, with limited dermal contact migration (Mikkelsen, Warming, et al., 2015).

Phthalates

Phthalates were similarly identified as chemicals for concern by RIVM, particularly Dicyclohexyl phthalate (DCHP), Diisobutyl phthalate (DiBP) and DEHP (Wassenaar et al., 2017). Research examining phthalates in clothing included a study of preschool clothes manufactured in Asia but purchased across the world, with Diethyl phthalate (DEP), Di-n-butyl phthalate (DnBP), DiBP, DMPP and DEHP detected in all samples, with six phthalates: DMP, DEP, DnBP, Benzyl butyl phthalate (BBP), DEHP, Dioctyle phthalate (DnOP) constituting most of the concentration of total phthalates, with some variation between country of origin and fabric type: cotton-spandex and cotton-nylon-blends having higher total phthalate levels and higher phthalate contamination in clothing of multiple synthetic fibres, possibly driven by recycling of polyethylene terephthalate (PET) bottles (Tang et al., 2020). Backpacks for children were analysed and DEHT found as the most common plasticiser with strong correlation between mass content of DEHT and mass transfer to wet wipes, used as a proxy to transfer to human skin (Xie et al., 2016). A study sampling baby waterproof fabrics, tarpaulin and printed fabrics found phthalates including DEHP in the waterproof and DINP in printed fabric above the Oeko-Tex Standard 100, indicating possible harmful exposure (X. Li et al., 2015). A study on white infant cotton clothing in China found phthalates in all samples, but they theorise that the main route for phthalate contamination was phthalates in “the surrounding air and environment of the store or manufacturer” rather than the materials itself (H.-L. Li et al., 2019).

Some of these studies identified daily risk: preschool clothes modelled both based on long-sleeve and short-sleeve outfits, they estimated the clothing an important source of dermal exposure relative to other skin-contact products. The authors identified summed DnBP and DEHP reproductive risk exceeding acceptable levels in 17.% of samples, but low carcinogenic risk (Tang et al., 2020). The white infant cotton clothing found DBP through skin contact to be the biggest contributor, but this dermal absorption far lower than house dust in the same area, with a cumulative risk assessment of median values “within the acceptable level” (H.-L. Li et al., 2019).

To summarise the evidence, it appears that a diverse range of chemical concerns may be present in textiles, many of which have been researched and are subject to international standards to limit the presence of harmful additives. However, there is little evidence to suggest that recycled materials are a notable driver of toxic chemicals in consumer textiles. Most research makes no mention of recycling at all, with chemicals instead being largely a result of the manufacturing, and particularly dyeing, process. There is some evidence to suggest that synthetic fibres such as polyester may lead to increased levels of bisphenols and heavy metals (particularly antimony). In addition, there is evidence of flame retardants in clothing items, however in a number of cases these are plastic accessories and often the results are not offered in enough detail to identify particular fabrics. The evidence is largely speculation, however, and in the case of bisphenols and parabens it appears that the presence of (non-recycled) Spandex is a more significant driver than, say, recycled polyester. This suggests that the materials used and additives purposefully used for material treatment, rather than the material’s recycled or non-recycled status, is more important for determining safety concerns.

It should be noted that with clothing, perhaps more than other products, the role of re-use may be of concern due to widespread clothes re-use. If additives from production stay in the garment, as many are expected to do (Assmuth et al., 2011), then older, now-regulated additives may be more likely to persist as a consumer risk through resale of old clothing than by the recycling of those materials into new products. This was not the focus of any of the papers so would be an avenue for future research, such as by testing explicitly older, vintage or second-hand clothing.

A summary of these results can be found in Table 2.

1.1.1.12.3 **Cosmetics**

A total of 9 papers covering 12 product datapoints were identified. An additional two datapoints which focus on post-consumer recycling, which includes some cosmetic packaging in the feedstock, were identified. Note that because our focus was on references to recycling, it is contamination of cosmetics through their packaging which is of interest. Specific searches relating to chemicals in cosmetics independent of any reference to recycling are likely to return many more results than we present here. Private testing of cosmetics to ensure compliance with regulation is likely to be widespread, with few of these results finding their way into academic literature. Indeed, a number of the papers identified were explicitly describing methodology improvements for use in such private laboratory analyses. The data relating to cosmetics in the EU Safety Gate reporting system (see the Technical Annex.) will likely be more relevant to understanding the regular harmful chemical in cosmetics.

The analytes mentioned are summarised in Table 17:

Table 17: Distribution of FD datapoints, cosmetics

Analyte	Number of datapoints
Bisphenols	1
Flame retardants	0
Formaldehydes	0
Parabens	4
Perfluorinated chemicals	0
Other Persistent organic pollutants	0
Phthalates	3
Heavy metals	1
Other	3

Of the 12 datapoints, a majority (57%) had no discussion of recycling. The datapoints relating to bisphenols and heavy metals did not mention recycling, suggesting no evidence at present that recycling is a route for their presence at harmful levels in cosmetics and personal care products. The identification of parabens, phthalates and other chemicals in studies with some discussion of recycling suggests that there could be risks related to recycled material from these chemicals. However, the very limited number of datapoints reduces confidence in any such conclusions and they cannot be said to offer conclusive evidence.

Of the datapoints where recycling was discussed, only one suggested recycling could be a source of contamination. As part of a review paper looking at over 200 chemicals in over 300 academic papers to trace common product groups, applications, and exposure routes, Li et al. (2019) found ‘personal care products’ to be a category in which Bisphenol A was most commonly reported (identifying six reports). However, this was far outweighed by 32 reports relating to Bisphenol A in food contact packaging. Given the scale of food packaging consumption, risks from contamination could therefore be more substantial than from cosmetics packaging. However, food packaging was out of scope for this review (see section 1.3). Li et al. (2019) also identified eight reports about exposure to the heavy metal lead (Pb) as a colourant in cosmetics, which has a dermal contact risk. They also found some 39 reports of the uses of phthalates in personal care products and 30 reports of phthalates in cosmetics, in both cases with functional use as a plasticiser and having risks through the pathway of direct contact with the product. However, their review did not identify papers specifically citing recycling-based contamination as a source. Instead, they discuss that “recycling could also lead to the occurrence of chemicals in recycled products, which might have completely different properties in retaining chemicals and different exposure patterns to human", but this is in the discussion of chemical exposure through products more generally and not specific to cosmetics (D. Li & Suh, 2019). Whilst the risk could be inferred, this does not amount to substantive evidence that recycling has any role in exposure to phthalates, Bisphenol A and Pb. For lead and phthalates it is explicitly mentioned that they are known additives with a clear role as colourant and plasticiser respectively.

There is some evidence, however, that chemical additives in cosmetics could subsequently be recycled into new products. A substance flow of parabens in Denmark highlighted the role of personal care products and mentioned that their packaging was not commonly washed out before disposal, leaving behind residues. If recycled, these residues may make their way into the recycling stream. At the time of publication, the authors state the packaging was not commonly recycled, however this may have changed since publication and may change further in the future (Eriksson et al., 2008). A more recent study from Germany provides direct evidence for this: in measuring post-consumer recycled plastic pellets, they found diethyl phthalate, which was expected to be present either as a plasticiser additive or as a trace contaminant from consumer cosmetics which were recycled. What is more notable from this German study into VOCs and SVOCs is that cosmetics were widely identified as a contamination source for post-consumer recycled plastic, but the analytes were primarily VOCs not in the scope of this study: alcoholds; aldehydes; ketones; lactones; esters, ethers; carboxylic acids – all were identified in post-consumer plastic likely to be contamination from cosmetics (Horodytska et al., 2020). Possible exposure or health risks related with the presence of these chemicals in post-consumer recycled plastic is not discussed.

Of the papers which did not discuss recycling, tests were conducted finding high concentrations of phthalates DEP and DBP (H. Chen et al., 2005; Llompart, Celeiro, et al., 2013); parabens (Melo & Queiroz, 2010; Msagati et al., 2008; Wang et al., 2017) and other chemicals not in our priority list including musks, organosiloxanes and linear siloxanes (Capela et al., 2016; Llompart, Celeiro, et al., 2013; Y. Lu et al., 2011).

The findings do not provide evidence towards the use of recycled content in cosmetics packaging. As a result, there are no identified human health risks. The literature on cosmetics and chemical risks focuses on known chemicals which are additives to the cosmetics themselves, not contamination from the packaging. However, the lack of reported negative results or studies looking at leaching from the packaging means it cannot be ruled out, as it may simply be that this kind of contamination has not been studied, and therefore represents an information gap. There is more evidence to suggest that, rather than recycled content contaminating cosmetics, cosmetics residues left in packaging which is then recycled could contaminate post-consumer recyclate. Whether the trace levels of chemicals in post-consumer plastic is a health concern or not is unclear and is an information gap for further study, though conclusion will likely be dependent on the final product into which it is made and exposure routes. If it is a health risk, this is likely something which could be mediated by either the restriction of these chemicals in cosmetics in the first place and better consumer engagement on cleaning packaging before disposal.

A summary of these results can be found in Table 3.

1.1.1.12.4 Electrical appliances and equipment

Total of 32 papers covering 36 datapoints were identified. The split of datapoints across analyte group is summarised in Table 18:

Table 18: Distribution of FD datapoints, electricals

Analyte	Number of datapoints (no recycling process papers)
Bisphenols	0
Flame retardants	26
Formaldehydes	0
Parabens	0
Perfluorinated chemicals	2
Other Persistent organic pollutants	0
Phthalates	0
Heavy metals	8
Other	0

Of the product datapoints, 19% had no discussion of recycling. The majority of electronics datapoints were therefore related to recycling. In addition to these product-focused datapoints, an additional 14 datapoints relating to the recycling of WEEE were identified and are discussed in section 2.1.4.3.No datapoints were identified in a number of the analyte categories: bisphenols, formaldehydes, parabens, other POPs and other analytes were not detected in the literature review. No phthalates datapoints were identified in product analyses, though phthalates were mentioned in one of the papers studying the recycling process, regarding occupational exposure of those living in e-waste dismantling areas (S. Lu et al., 2017). Evidence was not identified relating to the persistence of phthalates in recycled products.

Flame retardants

The majority of electronics datapoints related to the presence of flame retardants. Many of these focused on the recycling process, including studies on occupational exposure around WEEE recycling sites to PBDEs (J. Guo et al., 2015) and organophosphate flame retardants (S. Lu et al., 2017). Other studies focused on the concentration levels in waste and recycling streams and sorting processes at recycling sites including in the Netherlands (Leslie et al., 2016), Ireland (Drage et al., 2018) France (Hennebert & Filella, 2018), Europe (Salhofer et al., 2016; Wäger et al., 2012) and China (Y. Li et al., 2020; Salhofer et al., 2016). The details and conclusions from these papers observing the recycling process is detailed in section 2.1.4.3.

As common additives to electronics, flame retardants are often analysed in products with no suggestion that the contamination is due to recycling, but rather consistent with purposeful use. This includes tests of flame retardant residue in ovens (Gallistl et al., 2018); household information and communications technology (ICT) (Ionas, 2016); TV and computer housing and components (Choi et al., 2009; Kemmlein et al., 2003; Takigami et al., 2008); handheld electronics and accessories (Miller et al., 2016) and mixed household electronics (Keet et al., 2011; Turner & Filella, 2017a).

The growing relevance of e-waste recycling has led there to be a wealth of papers examining waste expected to be recycled, suggesting that they could act as the possible source of contamination: restricted POP-BFRs were found in high enough concentrations to classify most WEEE as POPs waste in England and Wales (Keeley et al., 2020), though results from Austria suggest heterogeneity within items, with 5% of components tested exceeding RoHS limits for bromine, suggesting further dismantling could “avoid cross contamination” (Jandric et al., 2020). This heterogeneity was corroborated by another Austrian study, observing that “levels of tetrabromobisphenol A (TBBPA) vary significantly even within the same category of waste” and “even amongst the same type of polymer” (Kousaiti et al., 2020).

In particular, television screens and computer monitors, particularly CRT screens were commonly highlighted for high flame retardant concentrations (S.-J. Chen et al., 2010; Choi et al., 2009; English et al., 2016; Keeley et al., 2020; Keet et al., 2011; Kemmlein et al., 2003; Peeters et al., 2015; Takigami et al., 2008). However, there is suggestion that this has changed over time: with progressive regulation of flame retardants (Charbonnet et al., 2020) and the move from CRT to flat screen monitors in which banned flame retardants are less prevalent, the share of e-waste plastics with banned flame retardants is expected to decrease in Europe (Peeters et al., 2015), with similar processes of flame retardant substitution observed in Japan (Kajiwara et al., 2011) and Czechia (Vojta et al., 2017).

Despite substitution, some authors suggest that banned substances will continue to be present in product streams. They suggest that “BFRs are present in most of the WEEE fractions worldwide and will continue to be present for the coming years” (Evangelopoulos et al., 2019), which is due to the process whereby “plastics from waste electrical and electronic equipment – and their additive flame retardants – are commonly recycled into low-quality black plastics” (Charbonnet et al., 2020). There is some suggestion that some of this WEEE recycling finds its way back into electronic products: low levels of a number of flame retardants were suggested to originate from recycling in mixed EEE samples (Drage et al., 2018; Turner, 2018b; Turner & Filella, 2017b; Vojta et al., 2017) and mobile phone casings (Yang et al., 2019). Additionally, WEEE recycling is the most clearly documented route for contaminant substances in plastics used for other consumer goods (see section 2.1.4.3).

Consumer health risks are well documented for flame retardants, with one review paper identifying 47 reports referring to ingestion-based dust exposure, 36 reports of inhalation-based dust exposure and 31 reports about dermal-absorption-based dust exposure (D. Li & Suh, 2019). However, the ubiquity of flame retardants as a functional additive means that it is not possible to isolate the possible risks – particularly *additional* risks – which may emerge from low levels of flame retardants which may have originated through use of recycled materials. The relatively lower concentration suggests that where electronics do present health risks, recycled content is not the major driver of that.

Overall, there is evidence that some EEE plastic is being made with mixed recyclate, and that this may lead to toxic chemicals being present. However, there is no evidence to suggest that this is a substantial driver of chemical safety concerns related to electronic products, with functional additives being the clear reason for chemical presence. There is substantial evidence to suggest that the concentration of toxic chemicals, most notably flame retardants and associated heavy metals (particularly lead and antimony) which had been purposeful additives to electronics in many cases make them unsafe to be recycled, suggesting that they should be treated as hazardous waste. Waste CRT televisions in particular are regularly highlighted as products of concern. Despite these concerns, there is also clear evidence that recycling of these potentially harmful plastics back into new products is happening, as is detailed further in section 2.1.4.3.

Heavy metals

Heavy metals were identified in eight datapoints. The detection of heavy metals Br, Cl, Sb, Ba, Sulphur (S) and Cd in ABS (Acrylonitrile Butadiene Styrene) suggest it is not suitable for physical/thermal recycling (van Oyen et al., 2015). At the same time, the levels of heavy metals Cd, Cr, Hg and Pb detected across a range of non-PVC electrical and electronic equipment (EEE) plastics "implies that many products may have been manufactured from a mixed recyclate" (Turner, 2018b).

Antimony is of particular concern: the inability to recover it from plastics suggest that its fate will be "incidental and unintended recycling" similar to that of flame retardants (Filella et al., 2020), and it is detected in such concentrations as to classify most WEEE as hazardous, with one study finding only large domestic appliances below this concentration (Keeley et al., 2020). Antimony concentrations in electronic products have been detected spanning three orders of magnitude, often highest in association with PVC or Br (Turner, 2018b) due to its use as a synergist flame retardant in white electronic casings (Filella et al., 2020; Turner & Filella, 2017b).

These findings suggest limited non-hazardous recycling applications of WEEE: one study suggested that even when recycled into 'safe' routes such as concrete, the lead in CRT screens and monitors make that concrete hazardous, resulting in a "three times larger volume of hazardous waste" in future (Bodar et al., 2018). However, a different study suggested that mobile phones contain heavy metals "below the limit values of substances regulated in the Restriction of Hazardous Substances (RoHS) Directive in China and Europe" (Singh et al., 2020), suggesting mobiles may be one form of electronic waste with less risk associated.

Perfluorinated chemicals

Two datapoints relating to perfluorinated chemicals were identified. One study from Norway identified PFAS at very low levels and PFOS in trace amounts in circuit boards, suggesting exposure to be "low in general", though mentioning such products could subsequently be recycled (Herzke et al., 2012). Another study looked at both household appliances and waste electronics, finding the summed concentration of fifteen perfluorinated chemicals at maximum levels of 11.7 and 2.2 µg/kg, respectively. The study concludes that the concentrations of contaminants "suggested that the presence of these compounds was not caused by the intentional addition of PFAAs or their precursors to the material during manufacturing", though they do not explicitly suggest recycling was the cause of contamination (Bečanová et al., 2016).

A summary of these results can be found in Table 4.

1.1.1.12.5 Toys

A total of 27 papers covering 38 datapoints were identified. The split of datapoints across analyte group is summarised in Table 19:

Table 19: Distribution of FD datapoints, toys

Analyte	Number of datapoints
Bisphenols	1
Flame retardants	17
Formaldehydes	0
Parabens	1
Perfluorinated chemicals	0
Other Persistent organic pollutants	2
Phthalates	7
Heavy metals	9
Other	1

Flame retardants, heavy metals and phthalates are the substances for which there was the most literature identified. There were no identified studies of formaldehydes or perfluorinated chemicals in the literature. The one out of scope analyte identified in a study considered here was formamide in soft plastic toys in Sweden, where all new products had levels below legislated limits, with one of seven old products exceeding Toy Safety Directive formamide levels (Pettersson et al., 2018).

Bisphenols

Bisphenols were considered in a study from Israel testing 20 parts of soft non-PVC toys. BPA was found in 22% of samples, and 17% of samples exceeded EU standards. The highest BPA level of 9.9 ppm (the EU standard is 0.1 ppm) was identified in a bath toy from a low-cost online retailer. There was no suggestion that recycling contributed to bisphenol presence (Negev et al., 2018).

Flame retardants

Flame retardants were the most abundant chemical group discussed in relation to toys and recycling. Often this was through tests for bromine used as a proxy for flame retardant presence, or as an initial screening stage for further analysis. The frequency of bromine detection was highly variable: datapoints include bromine detected in 36% of toy samples in Israel with mean concentration of 5.01 ppm (Negev et al., 2018); in 48 of nearly 200 samples (c.25%) in the UK, of which five exceeded the migration limit of 1000 µg/g, with maximum 16000 µg/g (Turner, 2018a); in 9% of another UK sample (Turner & Filella, 2017a); 15% of nearly 300 'leisure' products sourced in the UK which included toys (Turner & Filella, 2017b); 57% of 86 'toys and hobbies' samples also from the UK (Turner, 2018b); just under 40% of 87 toys in the US, most of which had lower than 100 ppm bromine (Miller et al., 2016); 32% of 47 toys in Czechia (Straková & Petrlík, 2017); regular bromine detection typically at below 0.1% weight in Australia (English et al., 2016) and so on. This points to substantial variation with regards to bromine content in the toys group, both in terms of frequency of detection and concentration levels.

In many cases, bromine screening was a first stage analysis before samples were tested for particular flame retardants, so many papers present results in terms of PBDE content, or specific commercial mixtures such as Octabromodiphenyl ether (octaBDE) or Decabromodiphenyl ether (decaBDE). Some notable results include one study of toys bought in China, of which all hard plastic toys had PBDEs detected with a median concentration of 53,000 ng/g, as well as in all stuffed toys and foam toys but at lower concentrations (S.-J. Chen et al., 2009); PBDEs found in all samples which had previously been identified for BFR content, of which BDE-209 (Decabromodiphenyl ether) was particularly prevalent with maximum concentration of 2500 mg/kg (Fatunsin et al., 2020); one quarter of toys in a sample from the Netherlands containing persistent organic pollutant-brominated diphenyl ethers (POP-BDEs) (maximum: 44 mg/g) and BDE-209 (maximum: 800 mg/g) (Leslie et al., 2016); 45% of samples taken around the world containing HBCD (maximum 1,568 ppm), of which 16% had concentrations above 100 ppm (Straková et al., 2017); nearly 100 Rubik's-style cubes, of which 90% and 91% contained octaBDE and decaBDE respectively, with 39% and 43% above 50 ppm respectively (DiGangi et al., 2017), and so on. Again, substantial variation is observable between and within study samples. For the authors of this research (many of the studies have been conducted by a small number of researchers each publishing multiple papers), the substantial variation between samples and findings of commercial flame retardant mixtures at levels often below what would be necessary for flame retardancy, in a product believed to have no need for flame retardancy, is evidence "that the recycling of BFR-treated electronic plastics has led to the unintentional BFR contamination of articles" (Fatunsin et al., 2020). This global, "quasi-circular economy" (Turner, 2018b) means that the legacy of toxic plastics "can be with us for quite some years to come" (Leslie et al., 2016), something which for some authors may result in "the loss of the long-term credibility of recycling" (Straková et al., 2017). The observational evidence identified about the recycling process in this review (section 2.1.4.3) supports the suggestion that e-waste is being recycled into new plastic products.

In most studies, chemical concentration was measured against legal limits as a proxy for acceptable or unacceptable health risks. Simulated risk exposures were carried out in a small number of papers relating to flame retardants. In the study of Chinese toy samples, inhalation, mouthing, dermal contact and oral ingestion were modelled, with the findings suggesting that BFR exposure from the toys likely accounts a small proportion of daily BFR exposure with hazard quotients far below one (S.-J. Chen et al., 2009). A subsequent study looked to improve upon this methodology by evaluating oral ingestion and dermal uptake of BFR-containing toys, finding that "while dermal exposure does occur for young children, exposure arising from accidental ingestion of plastic from toys is orders of magnitude greater". This accidental ingestion can make "a very substantial contribution to overall exposure" of young children to PBDEs and HBCDD, but this was found to be "well below the respective RfD values" both from toys alone and in the combined pathways. Only when looking at the maximum values in that study were estimates close to or exceeding limit values (Fatunsin et al., 2020). These limited findings suggest that, where identified at low levels due to recycling, there is not a substantial human health risk. However, as has been identified, heterogeneity of samples by orders of magnitude was common, and risks at the maximum values may be non-negligible, particularly for oral ingestion.

Heavy metals

Heavy metals were identified in ten studies. In one study of 14 soft non-PVC toys in Israel, the authors found trace metals at concentrations complying with the Israeli toy standard, equivalent to the EU standard (Negev et al., 2018). A similar study of new and used plastic toys in Sri Lanka found, amongst new toys, only lead at levels above the RoHS Directive (maximum 4,465 ppm) with all analytes (lead, cadmium, mercury, chromium, arsenic and bromine) found in 20/145 toys (14%). Amongst used toys, cadmium was above RoHS level with a maximum concentration of 147.94 ppm, with all analytes found in 10/27 (37%) of samples (ISO, 2019). The additional risks associated with older toys is corroborated by a study of approximately 200 second-hand plastic toys in the UK examining the risks of re-use rather than recycling. Barium, cadmium, chromium, lead, antimony were found in more than 20 (>10%) of samples each, with arsenic, mercury and selenium at lower frequencies. This suggests that restricted elements remain in toys “handed-down by parents, recycled via charity shops, and donated to nurseries, hospitals and schools” (Turner, 2018a). The role of old and second hand toys with cadmium and lead content is also highlighted in a recent review paper (Guney et al., 2020).

The datapoints which make more explicit claims about recycling-based contamination tend to focus on the role of antimony and lead. Antimony can be used “as a pigment, flame retardant synergist or residue from recycling”, making the exact route of entry hard to disentangle, though as a pigment it is usually found in yellow, brown and green products (Filella et al., 2020). Lead, similarly can be found in paint but is associated with end of life electronics. One sample of 86 ‘toy and hobby’ items from the UK identified no mercury presence in any sample, presence of cadmium in 5% of items, chromium in 13%, but much higher rates of antimony and lead detection: in 23% and 34% of samples, respectively often found alongside bromine, which led to the conclusion that black plastics were being sourced from end of life WEEE (Turner, 2018b). In another sample from the same author, some 54% of the antimony-containing samples also had bromine detected, and 56% of lead-containing samples also contained bromine (Turner & Filella, 2017b). In a third, antimony was detected in some 15% of samples in the ‘toy-hobby’ category, of which 29% were alongside bromine (Turner & Filella, 2017a). A final study detected antimony across samples from a range of countries, with the maximum EU value (4,716 ppm) being lower than the maximum non-EU value (6,620 ppm) (Straková et al., 2018). This would suggest that, other than their uses as functional additives, the highly heterogenous detection of heavy metals, particularly antimony and lead, is due to association with flame retardants and use in EEE plastics then being recycled. Many of these datapoints were identified in studies which also looked at flame retardants.

In most studies, chemical concentration was measured against legal limits as a proxy for acceptable or unacceptable health risks. The migration risks for heavy metals were simulated for 34 components under stomach conditions in one study. In eight cases, cadmium or lead migration exceeded the EU Toy Safety Directive migration limit, but for all other heavy metals studied the relationship between total and migratable concentration was not significant, which suggests that “total concentration is not, necessarily, a good proxy for exposure through ingestion” (Turner, 2018a). This point is similarly made in a review paper of heavy metals, which stresses a lack of correlation between *total* and *bioaccessible* concentrations of what they term ‘potentially toxic elements’ in toys, and suggest that approaches considering bioaccesibility instead of total concentrations are more important when regarding product safety for consumers (Guney et al., 2020). However, where content limits are in place, these products may still be in contravention of regulation for other, non-consumer safety reasons (such as environmental protection), regardless of exposure through migration.

Parabens

One review found some evidence of parabens methyl paraben (MP) and polypropylene (PP) in 17% of slimy toy samples, and MP as a binding agent in an artificial blood costume sample, as well as some limited detection of parabens in finger paint. In no cases was it suggested that recycling led to their presence, rather they seem to relate to purposeful additives.

Phthalates

For phthalates, one study suggested recycling as possible contamination, due to insufficient phthalate content to improve the properties of the material, suggesting they originated "from the use of recycled plastics or cross-contamination during the manufacturing process" (Ionas et al., 2014). Other studies included samples taken from low-cost vendors and street sellers in Saudi Arabia, where 19% of the tested products exceeded phthalate regulatory limits (Oteef & Elhassan, 2020), analysis and migration of phthalates from children's backpacks and toys (Xie et al., 2016) and non-PVC toys in Israel, all of which complied with European standards – though the authors point out that phthalates had previously been detected primarily in PVC toys (Negev et al., 2018). In Sweden, whilst new toys were within legal phthalate limits, in older items some 85% contained phthalates and in 14 of 52 toys sampled, the levels were 'very high', at levels up to 400x the current legislated levels (Pettersson et al., 2018). 49 toys sampled from Christchurch, New Zealand (where there is no regulatory control of phthalate concentration) where 65% has at least one phthalate at concentration of 0.1% mass, 35% containing multiple phthalates above 0.1% mass, which in worst-case combined exposure scenarios exceeded the hazard quotient, so may cause adverse developmental effects (Ashworth et al., 2018). In Denmark, toys and other children's items (bike handlebars, phone cases, watch straps) analysed found phthalate concentrations above 0.05% in nearly 1/3 of items; of those with concentrations above 0.05% most failed to comply with phthalate legislation. A risk assessment of products exceeding 1% mass (all non-toy items), however, suggested low risk due to limited skin absorption (Strandesen et al., 2015).

Regarding other analytes: one study considered 'dioxin-like' activity and polybrominated dibenzo-p-dioxins and furans (PBDD/Fs) in a selective sample of nine children's products, of which eight were toys, all made from black recycled plastic and shown to have PBDE presence above 500 ppm in previous analyses. The measured levels of PBDD/F "were on the scale found in a variety of hazardous wastes" including incineration bag filter ash and waste incineration bottom ash. Half of these products exceeded "the proposed chlorinated dioxin hazardous waste limit". This was found to be associated with the commercial DecaBDE mixture in e-waste, likely as an impurity in the e-waste which had subsequently been recycled (Petrlík et al., 2018). Therefore although this pertains to a POP detection, it is related to flame retardant usage and recycling. One study identified chlorinated paraffins in a small number of old toys and one new creative material toy in contravention of REACH (Pettersson et al., 2018)

In most studies, chemical concentration was measured against legal limits as a proxy for acceptable or unacceptable health risks. A smaller number of identified datapoints bridged the gap between chemical presence and human health risks through calculating risk assessments. For phthalates, the sample from New Zealand in isolation was not considered a risk of harm, but the exposures "represent only one source amongst a host of other", and in a combined exposure realistic worst-case scenario, may cause adverse developmental effects (Ashworth et al., 2018), by contrast the most notable toy migration risks in a Danish sample in a realistic worst case scenario still fell well below acceptable risk thresholds due to low migration and limited skin absorption of phthalates (Strandesen et al., 2015).

A summary of these results can be found in Table 5.

1.1.1.12.6 Furniture

A total of 22 papers covering 25 datapoints were identified. The split of datapoints across analyte groups is summarised in Table 20:

Table 20: Distribution of FD datapoints, furniture

Analyte	Number of datapoints
Bisphenols	0
Flame retardants	16
Formaldehydes	0
Parabens	0
Perfluorinated chemicals	5
Other Persistent organic pollutants	1
Phthalates	1
Heavy metals	2
Other	0

Flame retardants are clearly the substance for which there was the most available literature identified. For many analyte groups, no datapoints were identified, suggesting that these are not known to be present in furniture.

Of the datapoints, a majority (59%) did not discuss recycling. Of those which did, there was a roughly even divide between speculation that furniture was made using recycled materials and that furniture with toxic chemicals would subsequently be recycled into new products.

Flame retardants

The bulk of the literature identified related to flame retardants, which is to be expected due to flame retardancy legislation relating to upholstered furniture, such as in the UK and California and how these have changed over time with the phase out of pentabromodiphenyl ether (pentaBDE) and replacement of brominated flame retardants with non-halogenated organophosphate ester flame retardants (OPFRs) and alternative mixtures such as Firemaster 550 (Charbonnet et al., 2020; Environmental Audit Committee, 2019). One review identified nearly 50 reports relating to risk from flame retardants in furniture, primarily relating to dust exposure through unintentional ingestion and inhalation (D. Li & Suh, 2019). Nearly half of studies identified had no reference to recycling or disposal, but simply tested consumer products for PBDEs and OPFRs, including: curtains and carpets sampled in Belgium (Ionas, 2016), curtains in Japan (Kajiwara et al., 2009) and Korea (Shin & Baek, 2012), soft furnishings in Australia (English et al., 2016), in upholstered furniture foam (Kemmlein et al., 2003; Stapleton et al., 2009) and sofas in the US (Stapleton et al., 2012) and furniture in Denmark (Andersen et al., 2014).

Flame retardancy regulations are a key driver: samples from before the PBDE phase out in China did not have PBDEs, which the authors attributed to “lax furniture flammability standards” at the time (S.-J. Chen et al., 2010). Similarly, in New Zealand which has historically not had regulations requiring flame retardancy of household goods, <0.1% bromine was found in more than 85% of samples, that which was present being driven by imports as domestic manufacturers did not contain flame retardants (Keet et al., 2011).

Due to furniture’s long life-cycle, there is a risk that even if flame retardancy regulations are changed, now-banned substances such as PBDEs re-enter material streams through recycling. Some papers addressed this, suggesting that BDE-209 and HBCD were likely to be found in primary use, with penta- and octaBDE presence possibly from recycled materials, including recycled household equipment, car interior materials and WEEE (Vojta et al., 2017). Findings include curtains in Japan with BFRs in amounts inadequate to impart flame retardancy "implies the incorporation of recycled plastic materials containing BFRs", possibly from end-of-life electronic products rather than end-of-life furniture (Kajiwara et al., 2011); Irish mattresses, carpets and curtains with flame retardants above detection limits but below POP concentration limits (LPCLs) are likely due to migration from other products "or the result of using recycling products" in manufacturing (Drage et al., 2018) and rebound underlay for carpets known to include recycled content collected from Canada, Hungary and the USA had restricted PBDEs in 23 out of 26 samples, above the EU's POP restrictions in nearly half of samples. Interestingly, different carpet underlay samples from the same manufacturer contained "widely varying amounts and types of PBDEs", suggesting that variation was driven by the (recycled) raw material rather than by manufacturing practices and additives (DiGangi & Strakova, 2011). Another Danish paper identified bromine levels approximately 0.04% in office chairs, mattresses, rugs and armchairs, a level "hardly due to the content of brominated flame retardants" even though the authors do not speculate on the source (Andersen et al., 2014). As is speculated elsewhere, such low levels of unexpected substances could suggest some recycling-based contamination, though the authors do not draw this conclusion. The authors conduct a risk assessment only for TCPP and TDCPP in products on the Danish market. This contained both an analysis of risk and daily dermal, inhalation and dust exposure. The total exposure was measured, including both home interiors and other possible sources. They concluded from this that the bromine levels were below a concentration considered possibly harmful for health. In other cases, the health risks of BFRs is discussed more generally, but low-concentration samples possibly due to recycling are not tested to indicate if they amount to a consumer health risk.

The disposal routes and possible recycling of furniture is addressed in three papers: in Denmark, BFR-containing furniture and home textiles mostly goes to municipal incinerators, with no data on actual recycling identified (Lassen et al., 2014). In Ireland, furniture is identified as constituting 41% of the Irish waste which exceeds POP-BFR limits, with 76% samples of waste furniture including PBDEs, though none above the current LPCLs (Drage et al., 2018). One study in Japan highlighted tested how PBDE-treated curtains exposed to sunlight changed through photodecomposition to form polybrominated dibenzofurans (PBDFs), something which should have "close attention" paid to it in disposal and recycling (Kajiwara et al., 2013).

In summary, the research indicates that treatment to adhere to flame retardancy legislation is the key driver of the presence of flame retardants in furniture, leading the profile of flame retardants to change over time and vary between locations. There is evidence of small amounts of restricted flame retardants like PBDEs in furniture possibly due to recycling, though it is unclear if this is due to recycling of treated furniture or through recycled plastics, including e-waste, or both. The concentrations identified largely adhere to regulatory limits, apart from in the case of carpet underlay. However, the connection between these low levels of restricted substances and human health has not been sufficiently investigated for conclusions to be drawn.

Regarding other analytes, less evidence was identified and recycling was not considered as a possible source of those chemicals.

Heavy metals

For heavy metals, Aluminium (Al) and Sb were detected in high levels in curtains and carpets in Belgium, suggesting their use as a halogen-free flame retardant solution, with Sodium (Na) and Calcium (Ca) being found at similar levels, possibly as fillers (Ionas, 2016). Similarly, assorted furniture sampled in Denmark found widespread Al use, expected as a filler and Sb in small concentrations, correlated to bromine concentration (Andersen et al., 2014). In neither case was recycling considered the origin of the heavy metals, nor health risks discussed.

Perfluorinated chemicals
Perfluorinated chemicals were identified exceeding EU regulation for PFOS in office-chair leather and in some carpets sampled in Norway. Teflon-treated carpets had 6:2, 8:2 and 10:2 FTOH at levels ten times higher than in non-treated carpets, these FTOHs making up “more than 90% of the overall PFAS content of known PFAS in these products” (Herzke et al., 2012). Another sample of carpets found PFOS levels exceeding the REACH limit by five times (Bečanová et al., 2016), and a US study of a typical home identified carpets and home textiles as amongst the main sources of perfluorinated carboxylic acids (PFCAs) in a home (Z. Guo et al., 2009). The same authors found PFCA in products decreasing over time and suggest that over time, perfluorobutane sulfonic acid (PFBS) has been increasingly used as a replacement (Liu et al., 2014). In Swedish preschools, 8:2 and 10:2 FTOH were detected in new mattress covers and preschool furniture textiles and acrylic table cloths, all “intended to give good stain repellent properties” (Pettersson et al., 2018). In none of the cases was recycling identified as the possible source of contamination, with chemicals being associated with purposeful treatment (such as water or stain resistance). Herzke et al. do suggest however that the amount remaining on the carpet at end of life “is assumed to be disposed of with the carpet” (Herzke et al., 2012), so these could be possible sources of subsequent contamination through recycling.

Phthalates
Regarding phthalates, one study analysed two groups of preschool items used in Sweden: one group of old items, one of newer items. These samples included mattresses, furniture textiles such as table cloths, rugs and other floor coverings. In older products, phthalates DEHP, DINP and DBP were found above 0.1% weight in some rugs and mats, notably high in a slip-proof mat. In newer items, phthalate content was generally lower, but did exceed 0.1% for DEHP content in one mattress cover and DINP content in one snow play mattress cover (Pettersson et al., 2018). This same study also considered the POPs chlorinated paraffins: one old slip-proof mat and one new mattress were above the REACH limit for shot-chain chlorinated paraffins (SCCP). There was no indication that recycled content was the route by which either phthalates or chlorinated paraffins entered the products.

A summary of these results can be found in Table 6.

1.1.1.12.7 **Motor vehicles**
A total of 12 papers covering 15 product datapoints were identified in the motor vehicles category. One additional datapoint looking specifically at the recycling process of end-of-life vehicles (ELV) was also identified. The split of datapoints across analyte groups is summarised in Table 21:

Table 21: Distribution of FD datapoints, motor vehicles

Analyte	Number of datapoints
Bisphenols	0
Flame retardants	8
Formaldehydes	1
Parabens	0
Perfluorinated chemicals	0
Other Persistent organic pollutants	0
Phthalates	2
Heavy metals	2
Other	2

Flame retardants are the chemical group which were most identified as being present in motor vehicles. The chemicals out of scope identified included one estimate of PAHs from recycled tyres applied in children's playgrounds as rubber granulate, with PAH concentrations up to 19.8 mg/kg dry matter, falling well below regulatory limits (Bodar et al., 2018). One literature review of studies of the car internal environment identified the substances of highest concern in vehicles: benzene; naphthalene; formaldehyde; acrolein; crotonaldehyde; phenol (Larsen et al., 2017). What is notable is that only one of these chemicals (formaldehyde) is part of our priority list, suggesting that reducing consumer health risk in vehicles involves looking at other chemical groupings.

Of the datapoints, approximately one-third had no discussion of recycling. Of those which did discuss recycling, it was roughly evenly split between those looking at car parts which were possibly made of recycled materials and those looking at car parts which were expected to be recycled into new consumer products.

Heavy metals

The heavy metal antimony was found in 37% of vehicle part samples from the UK, at highest concentrations exceeding 1,000 µg/g in non-PVC panels, armrests and seats (Turner & Filella, 2017a). One study also identified lead above 1,000 ppm in vehicle parts (van Oyen et al., 2015). The association of antimony with flame retardants in some parts suggests its use either with purposefully added flame retardants in vehicles or due to use of recycled WEEE.

Flame retardants

Of the evidence relating to flame retardants, most looked at the possibility for ELV containing toxic chemicals to be recycled: one looked specifically at end-of-life vehicles which were being disposed of and recycled in the Netherlands. They estimated that 14% of POP-BDEs in automotive parts were expected to be recycled, and an additional 19% expected to be re-used, amounting to one third of POP-BDEs in motor vehicles retaining in use at end of life. They tested shredded ELV plastic and found POP-BDE concentration between <0.1-11 µg/g and BDE209 between 0.2-80 µg/g. In both cases, the concentration is lower in ELV than in WEEE, which was also analysed (Leslie et al., 2016). Similarly, in Ireland a study of ELV fabrics and PUF from a vehicle scrap site found PBDEs in 82% of samples, BDE209 in 88% of samples and HBCD in 30%. Only five samples (out of 119) exceeded limits, all in upholstery rather than PUF; most of these (80%) were in cars manufactured outside the EU. Based on Irish waste data, ELV amounts to 1.7% of all Irish waste which exceeds POP-BFR limits (Drage et al., 2018). These suggest that ELV could be a cause of restricted flame retardants entering new products. These contrast with an analysis of disposal routes in Denmark, which suggest ELV mainly "disposed of with shredder waste to controlled landfill", although the authors admit that data on actual recycling of BFR-containing waste in Denmark or the EU was not identified (Lassen et al., 2011).

In addition, some studies speculated that vehicle parts were being made from waste materials, leading to brominated flame retardant content. In the UK, one study found 24% of vehicle interior samples taken from three vehicles to have detectable bromine content (Turner & Filella, 2017a). In Czechia, sampled car parts found low HBCD levels and no BDE209, but PentaBDE and OctaBDE congeners were frequently detected, with ΣPBDEs being detected at median concentration of 1.22 µg/kg (Vojta et al., 2017), below the concentrations of the same flame retardants in household equipment. In China, PBDEs were identified in 80% of car plastic interiors (five sampled) with a mean value of 87,505 ng/g with a congener profile consistent to flame retardant consumption in China. The authors also look at recycled plastic, particularly recycled WEEE plastic, but it is unclear if that has contributed to the presence of PBDEs in the vehicles sampled (S.-J. Chen et al., 2010). Some studies of car parts had no suggestion that recycling played a role in flame retardant presence: one study in Australia cited in English et al. (2016) found two of 47 (4%) car carpet samples testing positive for bromine, with one sample elsewhere in the car having BDE209 at below 1ppm; similarly XRF analysis in New Zealand found bromine in a car seat, seat foam and hood lining (Keet et al., 2011) and a study of car interior foam and interior materials found PBDEs at a much higher level in the foam than material, of which BDE209 was the dominant substance. The authors anticipate this as purposeful addition, with the absence of DecaBDE detection due to its restriction worldwide (Shin & Baek, 2012). For purposeful additives, the time of manufacture will clearly be relevant in determining what flame retardants are present. A large sample of cars before restrictions on its use found DecaBDE the PBDE with highest concentration in car interior dust, for example (Gearhart & Posselt, 2006). The long-life cycle of cars means that ELV could still be sources of now-restricted chemicals.

Formaldehydes

Formaldehydes in car interiors were examined in one study, based on literature reviews, which compared two exposure scenarios. Formaldehydes are not discussed as exceeding tolerable limits in these scenarios, but aldehydes (acrolein and crotonaldehyde) and phenol were at risk of exceeding exposure limits. The same study included estimates of phthalates in the car indoor environment, with the suggestion that emissions of DBP and DEHP possibly change with temperature variation (Larsen et al., 2017). A similar conclusion was found in an earlier study of phthalates in automobile dust which found sunlight exposure and ventilation as playing a large role in phthalate presence, such as in cars in second-hand dealerships sat in the sun without ventilation (Gearhart & Posselt, 2006). As these studies looks at the indoor environment, it is not possible to tie these emissions to particular motor vehicle parts or their likelihood of that part being recycled.

A summary of these results can be found in Table 7.

1.1.1.12.8 Mixed product groups

A total of 18 papers covering 27 datapoints were identified which covered mixed, non-disaggregated product groups which contained at least one product group of focus. This does not include those papers mentioned in section 2.1.3.1 as being out of scope. The split of datapoints across analyte group is presented in Table 22.

Table 22: Distribution of FD datapoints, mixed product groups containing at least one focus group

Analyte	Number of datapoints
Bisphenols	2
Flame retardants	11
Formaldehydes	1
Parabens	0
Perfluorinated chemicals	1
Other Persistent organic pollutants	3
Phthalates	4
Heavy metals	2
Other	3

In many cases, the mixed product groups were analysed for a number of chemicals, though this was not always original product-specific analysis. In a study from the Dutch National Institute for Public Health and the Environment (RIVM) which combined literature reviews and expert interviews, evidence was identified for its substances of very high concerns (ZZS) list. This included bisphenols, formaldehydes, flame retardants, heavy metals, other POPs (namely short- and medium-chain chrlorinated paraffins) and phthalates/plasticisers, amongst numerous other chemicals: antimicrobial substances, solvents, antioxidants etc. Based on their research, they found 59 ZZS substances which could potentially be present in waste plastics – both recycled and possibly destined for recycling (Wassenaar et al., 2017 Table 5). Some applications for recycled plastic possibly containing these substances that they identify include carpet padding, office and kitchen products, clothes and footwear, furniture and design, automotive parts, packaging and others not within scope. However, the study does not present analysis of the scope of possible contamination or its risks. As they state, “actual data on ZZS presence in waste streams are often lacking” due to a lack of monitoring (Wassenaar et al., 2017).

Two papers looked at experiments conducted in Swedish preschools measuring concentrations of analytes in dust before and after following Swedish ‘chemical smart’ guidance, which centred around the removal of old articles and materials. In one, this included analysis of bisphenols, perfluorinated chemicals, flame retardants and phthalates from our priority chemicals. As they examined ambient air/dust contamination, the concentrations cannot be tied to specific products, but the preschool would contain furniture, toys, clothing and textiles, electricals and childcare equipment, all of interest. They identified significant declines in median BPA and BPF (Bisphenol F), but an increase in BPS (Bisphenol S). The poly and perfluoroalkyl substances were not tested prior to the intervention, but the post-intervention concentrations were “most of the times similar or lower than previous studies of dust in other indoor environments from Sweden and other countries” (Giovanoulis et al., 2019). Most PBDE concentrations decreased 20-30%. In all preschools, phthalate levels in dust decreased between 2%-60%. However, throughout there is no suggestion that these concentrations were related to recycled product, with emphasis being put on the age of items (Giovanoulis et al., 2019). The other study also considered flame retardants, but found no brominated flame retardants in either old or new products, only organophosphate flame retardants (Pettersson et al., 2018). The second study also considered chlorinated paraffins, with older items identified as having short-chain chlorinated paraffins in 9/79 (11%) samples, and medium-chain chlorinated paraffins in 13/79 (16%) of old products, but was only found in two new items out of 31 sampled (6%) – both of which contravened REACH regulations (Pettersson et al., 2018). This is suggested as being driven by age rather than recycling.

Other evidence related to chlorinated paraffins and their use in a range of products including PVC, sports equipment, toys, food packaging, rubber granulate, car tyres etc. suggests that the lack of labelling makes it difficult to track impacts and end-of-life, leading to possible challenges associated with recycling and reuse (Guida et al., 2020). This suggests possible contamination through recycling but does not quantify or provide evidence for that.

Other evidence for phthalates includes tests of the indoor retail environment in the US, where they were found to be abundant but at a mean concentration higher in residential than retail buildings (Xu et al., 2014). There was no suggestion that presence was driven by recycling, as functional addition is common. However, one paper from Denmark which sampled plastics from household waste, recycled and virgin plastics is illustrative as to risks of persistence when recycled. Phthalates were found in the majority of the samples, but found to not be being removed in the recycling of household plastics, possibly leading to subsequent contamination (Pivnenko et al., 2016).

Other chemical groups not in our focus list but identified through the searches in relation to mixed product groups included PAHs, found in a mixture of products including toys, tools, bicycle grips and sporting goods (BfR, 2010). Mixed products including toys, vehicle parts, electronics and food contact items have also been analysed for the presence of rare earth elements, which were detected to some level in 24/31 (77%) samples. They were least abundant in new electronic plastics, and most prevalent in samples with low levels of bromine – suggesting possible e-waste contamination. However, there was insufficient correlation between rare earth element and bromine concentrations, which combined with rare earth elements being found in consumer plastics without an e-waste signature (such as food contact), leading the author to conclude there may be “additional or alternative more general sources of contamination” during the manufacturing (Turner et al., 2021).

Most evidence relating to mixed product groups was related to flame retardants. These included in electronics, blinds and upholstery in India, where BDE-209 was identified as the predominant chemical found of this class (Kumari et al., 2014); in mixed consumer products including automobiles, electronics, toys and upholstery in Czechia, where HBCD isomers were detected in 83% of investigated products, although this was highest in construction materials (Okonski et al., 2018); PBDEs in the ambient retail environment, where concentrations were higher than in residential buildings (Xu et al., 2014). In none of these datapoints was there the suggestion that recycling contributed to flame retardant presence.

The presence of antimony has also been studied, in part due to its co-association with bromine from recycled plastic. One overview of the mixed product groups which contain antimony and association with bromine is instructive: it is found as a synergist in PVC, a PET catalytic residue and coloured pigment without association to bromine and can be found in a range of products including food trays, clothing, toys, watering cans, wire insulation and piping. When correlated with bromine, it is found as a synergist in electrical equipment or recycled from electrical equipment, the latter being found at concentrations ranging 50-3000 mg/kg in products including office equipment, toys, beads, toy handles, electrical products and food-contact items (Filella et al., 2020 Table 1).

Other datapoints tied the presence of flame retardants in plastics to possible recycling. One examined a mixture of textiles including textile toys, upholstery, furniture and home fabrics and found pentaBDE congeners and HBCDs in over 80% of samples, their principal component analysis suggesting that the samples "frequently consisted of recycled plastic materials" containing flame retardants (Vojta et al., 2017). Mixed plastic products from the US found bromine in 178/385 components (46%), of which 62% had concentrations lower than 1,000 ppm, which suggests below purposeful addition and therefore possible contamination (van Bergen & Stone, 2014). Similarly, in a sample of 1526 non-electronic products from the US, approximately 1/3 had bromine levels between 5-100 ppm, "suggesting unintentional contamination" (Miller et al., 2016); comparable to the findings from samples in the UK including Turner and Filella (2017b) and Turner (2018b) which are disaggregated and discussed elsewhere (see 2.1.4.2.4 and 2.1.4.2.5). Another sample from the Netherlands, of office and kitchen products manufactured from recycled plastic in the Netherlands had lower concentrations than both toys and recycled plastic pellets, suggesting that blending had reduced flame retardant concentrations to very low levels (<0.005 µg/g for office and kitchen products) (Leslie et al., 2016). None of these papers make the bridge between these product groups and human health risks. As has been summarised in other review papers, flame retardants have been found in a range of plastic products but the majority of those tested contained levels below the RoHS Directive threshold (Cook et al., 2020).

A summary of these results can be found in Table 8.

1.1.1.13 **The recycling process**

Most papers which refer to specific product groups infer the presence of recycled materials based on the concentration of analytes in final products. However, some studies were identified which looked specifically at the waste recycling process. Some 23 papers which analysed the recycling process in relation to harmful chemicals were identified. This section summarises the key findings from those in relation to the scope of this study.

1.1.1.13.1 **Persistence in recycling and migration risk**

One study by the Danish Environmental Protection agency offers a particularly useful summary of hazards associated with recycling plastics. They consider a range of chemicals, including those beyond the groups of focus here, the possibility of chemicals persisting in plastic during the recycling process and possible risks to consumers based on the potential of a chemical to migrate (Hansen et al., 2014). Table 23 has been based on the information in that study and provides useful context for the distribution of research and possible risks:

Table 23: Migration risk and persistence in recycling, by analyte group, based on Danish EPA findings.

Analyte Group	Persistence in recycling	Migration risk
Heavy metals	Due to strong binding, expected to persist through mechanical recycling process. Mercury typically found in polyurethane, which cannot be mechanically recycled. The fate of mercury in feedstock recycling isn't known, but most mercury is expected to have evaporated by that point.	Typically strongly bound, therefore not expected to migrate. As a result, the "exposure to consumers must therefore be considered low". Mercury an exception: not chemically bound, will migrate and evaporate, leading to some exposure risk. This risk is judged to be small.
Perfluorinated chemicals	Only used in certain types of plastics, and the fate of these substances by recycling is unknown. They suggest that "recycling is not normally practised".	These substances are not chemically bound, meaning there is a risk of migration.
Flame retardants	The fate in recycling depends on the plastic. Plastics which can be mechanically recycled (including PVC, PP, PS) will retain flame retardants during recycling. Newer, alternative flame retardants are less studied, characterised by "a lack of knowledge regarding both applications and fate in the products as well as by subsequent recycling activities".	Migration risk depends on the substance. Reactive flame retardants are chemically bound, and are considered of less risk. Additive flame retardants (such as most BFRs) are not chemically bound and will migrate easily, "and may thus result in significant exposure of consumers".
Phthalates	The migration rate is low enough to assume the main part of the plasticiser added to the product will remain in it until end of life. If mechanically recycled, they will "also be present in recycled materials".	Migration of plasticisers to food well studied. Generally, all plasticisers "must be anticipated to migrate and the use in plastics should thus be considered a source of exposure to consumers".
Bisphenols	They judge that if Bisphenol A is present in mechanical recycling, it will remain in the plastic.	Based on its physical properties, it should be regarded as a semi-volatile compound, able to migrate out of plastics. With time, "the major part of the substance will probably be released by leaching to the surface followed by evaporation or removal by washing".
Formaldehydes	In mechanical recycling, unreacted formaldehyde will likely evaporate due to its low boiling point and the high vapour pressure. As a result, "the substance will most likely not be present in recycled materials".	Its physical properties suggest it should migrate strongly. This strong evaporation could lead to occupational exposure.

Note that the study is looking only at plastics. Neither parabens nor other persistent organic pollutants (i.e. those which do not fit into another category considered, in line with the grouping detailed in section 1.3.2) were considered to be present in plastics (Hansen et al., 2014 Appendix A). As a result, these results cannot be extended to all consumer products including clothes, textiles, home fabrics etc., but this summary does offer a useful indication of possible recycling contamination risk and possible consumer risk based on the product. From this, some conclusions can be drawn which are broadly consistent with the distribution of research as detailed in the heat matrix (section 2.1.4.1). The relative lack of research on parabens and other persistent organic pollutants is consistent with their not being present in plastics, and the relative lack of research on formaldehydes and perfluorinated chemicals is consistent with the suggestion that they either are not recycled or would not be present in recycled materials. A small amount of information was identified for bisphenols and phthalates, whereas a large amount was identified for heavy metals and flame retardants. Within these latter groups, it is unclear if the distribution reflects relative risk of these materials in recycling, or if it relates to other biases such as research and political saliency.

1.1.1.13.2 **Summary of identified data**

A total of 23 papers were identified with relevant information relating to the persistence of harmful chemicals during the recycling process. The distribution of datapoints from these papers across analyte groups is displayed in Figure 2:

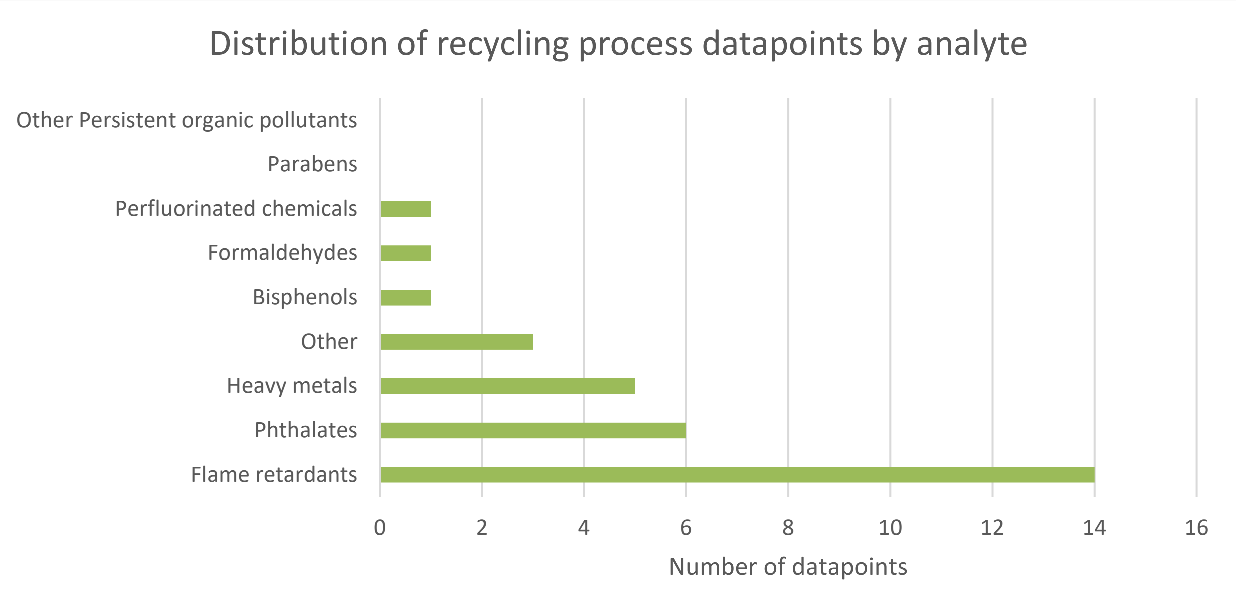

Figure 2: Datapoints relating to the recycling process, by analyte group

Where ‘other’ relates either to papers which did not analyse specific chemicals but did look at the recycling of a key product group (such as WEEE), or to lists of chemicals, notable volatile organic compounds (Considered in papers including Cook et al., 2020; Horodytska et al., 2020; S. Lu et al., 2017). Note that the sum of datapoints exceeds the number of papers as some papers, included datapoints on multiple chemical groups.

When considered by the product groups described (Figure 3) it is harder to draw trends due to the dominant category being mixed waste. This is due to a number of studies relating to post-consumer waste, household and business waste which by nature is often mixed. As a result, it is likely that some of the priority categories could be present in these mixed wastes, but it will also clearly have a large presence of products such as food contact packaging. However, as post-consumer mixed recycling may then be used to create new consumer products in our priority categories, these studies were still considered relevant. Other than mixed waste, there is a disproportionate focus on electrical appliances and equipment, consistent with the findings in the analysis of products (section 2.1.4.2).

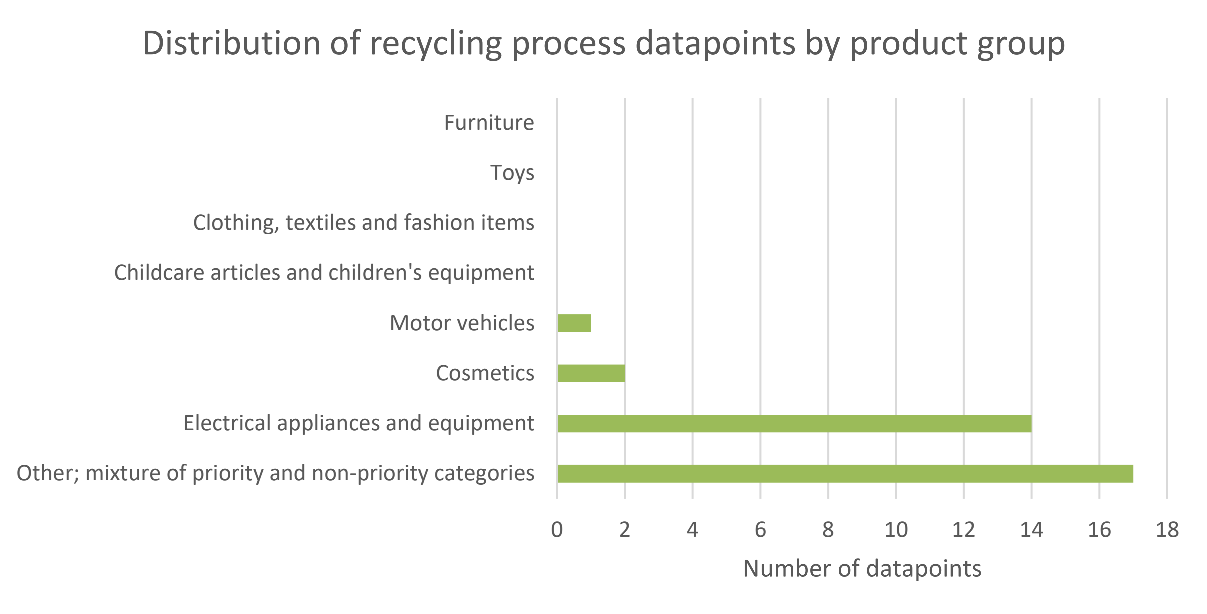

Figure 3: Datapoints relating to the recycling process, by product group

1.1.1.13.3 **Global**

In the identified studies on recycling processes, the global nature of production and recycling of consumer goods is emphasised. Complex global trade flows are a barrier both to understanding and accountability, with different standards and regulations in different parts of the world. Illegal trade further limits the ability of regulation on recycling of possibly toxic materials to be effective. Even more so than the explicitly illegal trade, the role of informal recycling seems to be particularly important due to the scale of the sector in many countries as well as the fact that it is largely unregulated. For the case of WEEE, this global complexity is put clearly by Turner (2018b), who suggests that in emerging economies including India, Pakistan, Nigeria and China, stockpiles that include older WEEE and restricted BFRs may be processed by inexperienced operatives without suitable screening technology at informal or unregulated facilities", leading to a "complex, poorly quantified and largely undesirable and unregulated quasi-circular economy".

Consistent with the distribution of focus analytes and products, by some distance the most identified distinct product group and analyte group is related to electrical appliances and flame retardants (see Figure 2 and Figure 3). The focus is partly because of the scale of WEEE and its growing importance; it has 3-5% yearly growth, but in 2016 just 20% of global e-waste was properly recycled or disposed of, the remaining 80% undocumented, with a very substantial share believed to be illegally exported from regions such as Europe to countries where WEEE is recycled (Ilankoon et al., 2018). Whilst disposal of WEEE to recycling routes may be a result of recycling targets in the regions such as Europe, the economic driving force of their subsequent recycling in the recipient countries is the metallic fraction. This can create problems as the plastics could become an after-thought, but in some cases these plastics need attention paid to them to remove certain regulated substances, such as regulated brominated flame retardants. One recent paper estimated the current stock and emission of PBDE congeners worldwide using a 'dynamic substance flow model'. Whilst they estimate approximately 80% PBDEs in waste destined to landfill, some 6% is subject to inappropriate waste treatment and a further 5% of total PBDE waste is inadvertently recycled, mostly in less industrialised regions (Abbasi et al., 2019, fig. 5). This amounts to some 70 kt of PBDEs and BDE209 from 1970 to 2018 being recycled, indicating the scale of the problem.

The trade is global but the flows are uneven, with waste flowing from industrialised to less industrialised and emerging economies, and then re-imported in the form of consumer goods. In emerging economies recycling is often "practiced in a largely unregulated artisanal industry employing simplistic, labour intensive and environmentally hazardous approaches" (Ilankoon et al., 2018). This means that exposure to detrimental health effects from waste disposal and recycling is concentrated is less industrialised regions: Abbasi et al. estimate that 70% of waste disposal emissions of PBDEs occurs in less industrialised regions, whereas 70% of the production was in industrialised regions, meaning that "emissions and exposure to harmful chemicals in long-lived products may, therefore, be disconnected in both space and time from the areas where relevant products were initially produced and/or used" (Abbasi et al., 2019). As a result, the exposure of workers and communities in countries which reprocess waste is of particular interest and concern with well-documented negative health effects. This is not within the scope of this study, but should be noted as a particular concern for recycling of products with toxic chemicals, most notably WEEE (Cook et al., 2020; See, for example: Hoang et al., 2021; Kajiwara et al., 2011; S. Lu et al., 2017; Sepúlveda et al., 2010; Zhuang, 2019)

As a result of this global unevenness, a meaningful distinction can be made between OECD and non-OECD nations in regard to recycling processes.

1.1.1.13.4 **Non-OECD countries**

The evidence on hazardous chemicals in recycling in non-OECD nations was centred around WEEE. There is evidence that WEEE is regularly recycled, including its plastics. Some recent studies have simulated the recycling process by taking pre-recycled plastic from e-waste sites in China and converting them to recycled plastics through thermal extrusion experiments. In one, PBDE and HBCD content was tracked from pre-recycling to recycled plastics, finding some 77% of PBDE remaining in the recycled pellets after extrusion under thermal conditions; 39% of HBCD. The concentrations of PBDE and HBCD in these recycled pellets were comparable to those in plastics from typical recycling manufacturers in China and comparable to products identified in other studies. The authors conclude that "recycling is not only an important way for PBDEs to persist in the life cycle, but also an inevitable fate for PBDE's ubiquitous presence in daily-use products". Based on relative PBDE content in pre-recycled WEEE, they speculate that "obsolete TVs are the major source of PBDEs entering into the recycled materials flow" (Y. Li et al., 2020). The high-PBDE content of televisions is a recurring theme (J. Guo et al., 2015; Kajiwara et al., 2011), suggesting their disposal is of particular concern. A similar study looked at heavy metals of newly recycled plastics, finding Pb and SB levels in recycled plastics exceeding regulatory limits (the Toy Safety standard) and clear leaching effect of Ni, Cu, Zn, Sb and Pb after ageing, which could pose possible health risks. In these ageing plastics, "heavy metals were easily migrated outwards" (Mao et al., 2020). These give clear evidence which supports the suggestions made elsewhere that the low levels of flame retardants and heavy metals in plastic products could be from the recycling.

Likewise, there is evidence that WEEE is not systematically sorted to remove BFRs. In one study, 12 Chinese recycling facilities were visited and whilst, they were dismantled and sorted, "no separation of plastics with brominated flame retardants was observed in the visited plants" (Salhofer et al., 2016). In Chinese recycling, there has historically been a divide between informal and formal sectors, with a strong informal sector recovering higher value WEEE. In informal sectors, regulation is less likely to be adhered to, with negative effects both environmentally and for worker health (Awasthi et al., 2018). There is evidence in India that informal recycling leads to contamination of recycled plastic with brominated flame retardants. Haarman and Gasser (2016), for example, traced the informal recycling sector in Delhi, the city where some 30-40% of WEEE generated in India ends its life. They found that polymers were rarely sorted for flame retardancy, with recyclers having no incentive to separate these pieces and not recycle them. As a result, “most BFR plastics end up in the main streams” and are sold at markets for below virgin plastic prices, leading to regular downcycling into lower quality consumer products including toys, buckets or car parts.

1.1.1.13.5 **OECD countries**

Several papers were identified looking specifically at the recycling process in OECD countries, including mixed household waste which was expected to be recycled and consumer materials which were known to be recycled. WEEE and flame retardants were again notable areas of focus.

In Europe, recycling processes are generally considered to be more technologically advanced and involve the dismantling and mechanical processing of equipment including sorting by sensors (Salhofer et al., 2016). Pre-recycling WEEE needs to be broken down into parts which can then vary substantially in the distribution of flame retardants. One study of over 4,000 parts from 347 pieces of WEEE equipment in France found 363 parts with >100 mg/kg bromine, with high heterogeneity of bromine concentrations in plastics (Hennebert & Filella, 2018). Sampling of mixed WEEE categories typically processed in Europe found “no mixed plastics fraction from WEEE is completely free from substances regulated in the RoHS Directive”, with variation between item types: CRT monitors and TVs having highest flame retardant content and flat screen monitors the lowest in these samples (Wäger et al., 2012). Sorting is therefore key: Hennebert and Filella (2018) identify in particular the sorting of small household appliances, CRT and flat screen plastics as necessary “to avoid uncontrolled dispersion of regulated substances in recycled raw materials”. However, even in Europe the sorting may not filter out contaminants: based on Dutch data, some 22% of the POP-BDEs in WEEE was expected to end up in recycled plastic. The authors tested samples of WEEE, ELV and recycled plastic pellets for POP-BDE and BDE-209. Both were found in all three samples: higher in WEEE (ranging 2-330 µg/g for POP-BDE and 6-3300 µg/g for BDE209) than shredded car plastic (<0.1-11 µg/g and 0.7-70 µg/g respectively). The recycled plastic pellets they sampled had concentrations between <0.7-67 µg/g and 5-210 µg/g respectively. This suggests that even where sorting takes place, it may not always be adequate for screening out harmful chemicals.

Evidence from New Zealand similarly focuses on flame retardants, particularly the PBDEs pentaBDE and octaBDE. The study found that “there are very few articles containing commercial PentaBDE and OctaBDE that are recycled in New Zealand” as most recycled polymer articles are packaging and food contact, where the PBDEs were not expected to be (Keet et al., 2011). An interesting conclusion from this particular study is that the 0.1% weight limit on BDEs in polymers has raised awareness on their concentrations and means that “polymers with levels below 0.1% have value as recyclable materials”. This implies a level of trust in the current safety limits both as being adequate and not being expected to change, suggesting that low levels of contamination, as long as it remains below legal limits, are not a concern and should be recycled. In this case, a strategy of 'blending' polymers with restricted substances with 'clean' or virgin plastics could be considered appropriate. A blending approach for WEEE is one of the strategies considered by Wagner et al. (F. Wagner et al., 2019), although they also stress that "for this strategy the compliance to legislation and the avoidance of restricted substances to enter the recycling streams needs to be safeguarded" and that "long-term effects need to be estimated case-by case", suggesting a more cautious embrace of the idea. This is a noticeably different tone to some of the papers cited elsewhere which expressed concern at the presence of harmful chemicals even below legal limits (S.-J. Chen et al., 2009; Ionas et al., 2014; Straková et al., 2018; See, for example: Straková & Petrlík, 2017).

As well as evidence relating to WEEE, some studies examined mixed residual and business waste going to recycling and compared this with virgin and recycled plastics. A number of these studies were conducted in Denmark: Pivnenko et al. conducted two studies of seemingly the same waste samples, first for phthalates (Pivnenko et al., 2016) and secondly for BFRs (Pivnenko et al., 2017). They sampled a mixture of waste destined for recycling: mixed residual, source segregated residual and business (both from Denmark) and virgin and recycled processed plastics from China, Denmark, Germany and the Netherlands. Eriksen et al. (2018) similarly looked at Danish household waste alongside reprocessed and virgin materials from European and Chinese metals but focused on heavy metals.

Regarding phthalates, Pivnenko and colleagues detected DBP, DiBP and DEHP most frequently. The source of the material was the biggest driving factor for phthalate content. They found an insignificant difference between waste samples and in recycled household plastics, suggesting that phthalates are *not removed* during or following recycling, and could potentially persist through this process. Household plastic samples having higher phthalate samples than pre-consumer plastics suggests they may be being added in later manufacturing stages, such as labelling or gluing (Pivnenko et al., 2016). Lee et al. (2014b) analysed the flow of phthalates through production, consumption, waste treatment and recycling of plastics in Europe. They estimate that in total, approximately 4% of the DEHP and BBP and 18% of DBP annual demands in Europe as raw materials re-enter the product cycle with recycled plastics and paper, with 2-12% of the phthalates re-circulating in Europe. However, they highlight food packaging as a particular exposure route; non-food consumer products with recycled materials were not assessed. In a study modelling EU recycling targets, Lee et al. (2014a) estimated that by 2020 the amount of phthalates DEHP, BBP and DBP re-entering the product cycle would be in the range of 70% to 310%, meaning that even if phthalate production is reduced, the amounts re-entering the product cycle would increase due to recycling of plastic and paper. However, this considers recycling from all sources, including waste paper, food contact packaging etc.

When the Danish samples were analysed for flame retardants, the sample for household waste and recycled plastics had the highest frequency of BFR detection, particularly polystyrene (PS) and acrynlonitrile butadiene styrene (ABS) samples. Based on the evidence, they suggest that PBDEs in processes waste could be "attributed to contamination through recycling, i.e. when older plastic products containing PBDE are recycled into new plastics" (Pivnenko et al., 2017). It is not clear where the recycled plastics originated from.

The study on heavy metals found substantial variation between samples which was driven by both polymer type and origin of plastics. Household samples – both waste and reprocessed – contained higher Al, Pb, Titanium (Ti), Zn when compared to virgin samples, however these "did not exceed the few legal limit values currently available" apart from a single sample. Generally, washing could not explain differences in detection, suggesting that it was not driven by contamination in the recycling stream, but rather material makeup. The origin of these materials, whether contamination or purposeful additives to the plastic, are unclear.

Another study of post-consumer recycled high-density polyethylene (HDPE) and low-density polyethylene (LDPE) from Germany identified the SVOCs and VOCs of which were most present. They found that other than cosmetics residue, rotten food, organic waste as well as lubricants and adhesives were the main contaminants of post-consumer recycled plastic, suggesting that contamination of consumer recycling may be more driven by food contact packaging than the product categories considered here (Horodytska et al., 2020).

Discussion

The findings and conclusions of this literature review are summarised in section 2.1. The following sections provide some elaboration on the key points raised in that summary.

1.1.1.14 Trends in product chemical hazards

As identified across the high level summaries of datapoints (section 2.1.4) and product group tables (section 2.1.2), there is a varying degree of evidence for harmful chemical presence in the product groups of interest. In the FD, the product groups for which the most evidence was identified were electricals, clothes and toys. The products for which the least evidence was identified were cosmetics and motor vehicles. When considering only the ERD, the product groups for which there was the most evidence remain electricals, clothing and toys but some interesting trends are identified. Noticeably, that childcare articles, cosmetics, clothes and furniture are all under-represented in the recycling-explicit literature (see Figure 1). That is to say that when papers do study chemical hazards in these product groups, they are *less* likely to make reference to recycling than other product groups. By contrast, electricals, toys, motor vehicles and the other (mixed) product group were overrepresented in the recycling-explicit literature. This suggests that, when authors study chemical presence in these groups they are more likely to make some explicit connection to recycling.

On aggregate, the chemical groups for which the most evidence was identified across the FD were by some distance flame retardants, followed by heavy metals and phthalates. Very little evidence was identified for other POPs, parabens, formaldehydes and bisphenols. Broadly the same pattern held true in the ERD, with the notable exception of phthalates and perfluorinated chemicals, which were both substantially under-represented in the recycling-explicit literature. This would suggest that, where these chemicals are identified in consumer products, authors are less likely to speculate on the role of recycling, suggesting that they are more likely to be a result of purposeful addition. By contrast, flame retardants and heavy metals are over-represented in the recycling-explicit literature, suggesting that they are the analytes of most concern in regards to possible recycling-based contamination. Often, they were studied together due to the use of some heavy metals as a synergist flame retardant, most notably antimony; some 1/3 of heavy metal datapoints only measured the presence of antimony. Whilst distinct groups, therefore, there is substantial overlap in the possible avenues for recycling-based contamination.

1.1.1.15 **Contamination through recycling**

The evidence pertaining to recycling was limited. The FD included all papers, but the ERD contained only those which had some suggestion that recycling could play a role. Of the FD datapoints relating to the chemical content of products, approximately half of the papers identified were in the ERD – in other words, only about one in two datapoints identified by our searches (see section 2.1.3) bore any connection to recycling. This includes those datapoints, which were particularly relevant for electricals and motor vehicles, where the analyte was expected to be purposefully added but the product could subsequently be recycled at end of life. Nearly two-thirds of datapoints which included discussion of recycling, however, suggested that recycling-based contamination had already occurred in the product, through use of recycled content. In nearly all cases, the 'evidence' that recycling could have played a role in product contamination was speculative, based on reasoned conjecture from the presence of unexpected analytes at lower levels than would be required for imparting functional qualities into products. This greatly reduces the confidence in conclusions regarding the role of recycling.

Despite clear limitations in the data, from the evidence found, a picture does start to emerge which helps to illuminate and contextualise the analyses of final consumer goods. This picture centres around the role of WEEE plastics, particularly those which have been treated with flame retardants and associated heavy metals, particularly antimony, lead and to a lesser extent cadmium. These are the analyte groups which are referenced most regularly, and WEEE recycling is highlighted as the principal avenue through which these chemicals may be unintentionally entering consumer products. Based on the scale of the evidence, particularly the direct observation of WEEE recycling (see section 2.1.4.3), we can state with some confidence that this recycling is occurring and that restricted chemicals are entering some consumer products. This particularly appears to be the case for black plastics. This may be happening "unaware to the consumer and, in many cases, the manufacturer and retailer", as one researcher who has conducted numerous studies into the issue suggests (Turner, 2018b). The lack of evidence of other chemical groups does not necessarily rule them out, and the distribution of evidence identified may reflect biases in the academic literature (see section 2.1.5.4) More research would be needed to confirm or reject the hypothesis of recycling-based contamination through other avenues.

WEEE plastic is of particular concern due to its recycling in informal and unregulated processes in emerging economies. In some cases, WEEE is not sorted for the exclusion and proper disposal of brominated plastics, leading to the persistence of flame retardants and associated heavy metals finding their way into plastic pellets. TV housings appear to be of particular concern due to their chemical makeup and the substantial scale of the waste stream. Where plastic recycling is largely informal, the incentive system may not align with the removal of hazardous materials, leading to its persistence in recycled pellets. This lack of sorting and mixture with non-brominated plastics means it can reasonably be expected that these chemicals will be unevenly distributed both within batches of recycled plastic and between them, even from the same facility. This could make testing difficult and lead to substantial variation in results – which is consistent with the findings of product analyses for flame retardants and heavy metals.

This is not to suggest the problem relates only to emerging economies. Whilst the evidence is limited, it does suggest that contaminated materials can persist in recycling processes in OECD nations, in part due to imperfect sorting and contamination of mixed household waste. However, the risk of harmful chemicals will be shaped by how the recycled content is then used. The risk of WEEE recycling in countries such as India and China is magnified by their role as manufacturers of many cheap consumer goods which are then exported to the UK – and all around the globe. The implications of this process are not just for UK consumers.

1.1.1.16 **Implications for consumer safety**

Few studies made an explicit connection between chemical presence and human health risk. Those that did often framed the issue around legal limits, comparing concentrations of analytes against a legal or voluntary benchmark. The results were inconclusive: most products tested in the literature cited had concentrations below legal limits, but a non-negligible number of products substantially exceeded legal limits, suggesting some grounds for concern.

The risk to consumers is partly determined by the migration risk or bioaccessibility of a chemical, which is in part determined by how the product is interacted with. Far fewer studies examined this, though a small number did, particularly for items which may be interacted with in ways which increase risk: clothing and accessories which are worn against the skin, carpets and rugs which may be crawled and slept on by infants, toys which may be chewed on or accidentally ingested by children and so on. Generally speaking, the studies which conducted migration tests were *not* those looking at the presence of recycled content but were rather measuring the risk of chemicals which were functional additives. Only a very small number – notably some for the toys category – did look at the risk of chemicals believed present due to recycling (see section 2.1.4.2.5). In these cases, even though some toy parts greatly exceeded legal limits, risks were only identified in worst-case scenarios. However, clearly the risk to consumers from recycled content, where it is believed to be present, remains a gap in the knowledge.

1.1.1.17 **Limitations and possible biases**

The conclusions of this literature review are limited by a number of potential biases which should be understood as caveats to the conclusions. In particular, there may be biases in the way that chemical presence and recycling-based contamination are studied. These limitations are similarly highlighted in a review paper of health risks of chemicals in consumer products which did not focus on recycling (D. Li & Suh, 2019).

Firstly, researchers may be influenced by positive results bias, where research is geared towards re-creating existing findings and reporting positive results, rather than exploring other possibilities and reporting negative results. As Li and Suh phrase it, “negative studies (i.e., studies that result in no observable effects) rarely get published, and that peer-reviewed publications are widely used as the primary measure of research productivity in academic and research institutions, the list of chemicals targeted by funded research tend to be biased toward the ones with known health risks” (D. Li & Suh, 2019). The same logic may apply to product groups. As a result, a small number of high-profile studies into the intersection of a particular product group and harmful chemical (such as toys and flame retardants) could lead subsequent researchers to examine the same issue. Governmental and industry research, less bound by the structural incentives of positive results, could help in ensuring the more avenues are explored.

Secondly, political saliency may drive the direction of research. E-waste is a material stream growing rapidly in volume and importance and this may lead to heightened research interest. Similarly, products like childcare articles and toys are emotive issues by virtue of children being the intended user of the item. The safety of these items may be given more importance than the safety of some other items, leading to increased interest by both researchers and regulators. Particularly stringent regulatory attention to toys was anecdotally highlighted by stakeholders in the industry workshop (see section 4.0).

Thirdly, methodological biases may encourage interest in certain chemicals. Many of the papers studying flame retardants and heavy metals deployed a handheld XRF analyser, something which may not be applicable for all chemical and product types. In some cases, the XRF was used as a pre-screen for sub-samples to be further analysed through in-depth laboratory analysis such as by use of gas chromatography-mass spectrometry (GC-MS) system. The relative costs of machinery and time taken for analysis may allow more research with larger samples to be published more frequently.

What these biases imply is that, although the evidence points clearly towards the recycling of WEEE into new plastic products as *an* issue, it does not discount that other recycling-based contamination could also be happening. The results are therefore limited by likely painting an incomplete picture of the issue.

As well as the issue of robustness, some other limitations should be considered. First and foremost, the ‘evidence’ of recycling relies in nearly all cases on speculation. It is possible that the material contamination could have come from other avenues, such as manufacturing or transport cross-contamination, or manufacturing defects. A central problem here is the lack of traceability of recycled materials and the substantial heterogeneity within samples. In many cases, it is feasible that products are not purposefully using recycled plastic and are simply driven by price, and that mixed recycled plastics may be both cheaper and not labelled as having restricted chemicals present. The retailer or manufacturer of the product may therefore be unaware of the origin of those plastics. The inconsistency could mean that within a single batch of plastic products, some samples exceed regulatory limits and others do not. This makes testing, enforcement and understanding the risks associated very difficult.

Another limitation is that the studies cited rarely made sufficient distinction between the origin and quality product tested, or did not present information disaggregated in a way to explore how this might influence chemical composition. Based on the evidence here, WEEE plastics may be recycled into cheap, blended plastic pellets in countries including India and China. These are then likely to be used for cheaper, lower quality goods. Whilst many products will be manufactured in China, this information alone may be insufficient to tell the difference between products manufactured by certified and ‘reputable’ companies and those by unbranded, ‘disreputable’ manufacturers. This distinction between the ‘reputable’ and ‘disreputable’ sides of industry was one highlighted by stakeholders (see section 4.0) as an important distinction, but the evidence in the literature generally makes insufficient distinction between the two. This is an evidence gap which would help to understand the problem.

Overview of legislation and standards relevant to recycling and consumer products

This section summarises the legislation that governs and the standards expected of all parties and stakeholders involved in the use of recycled material.

Legislation

Following the UK's withdrawal from the EU and the subsequent transition period, a range of legislation has been brought into UK law under the European Union (Withdrawal) Act 2018. Key legislation is highlighted in the following section.

1.1.1.18 The Waste (Circular Economy) (Amendment) Regulations

English and Welsh law was updated through the Waste (Circular Economy) (Amendment) Regulations 2020 to include changes to the Waste Framework Directive (WFD) made in 2018.

The Regulations provide the overarching legislative framework for the handling of waste. The Regulations sets the basic concepts and definitions related to waste management and waste management principles such as; the Waste Hierarchy, the Polluter Pays Principle and Extended Producer Responsibility. The Regulations implement the Waste Framework Directive objectives to reduce the environmental impact of waste and to encourage resource efficiency through reuse, recycling and recovery (European Commission, 2008).

The current version of the directive sets recycling targets of 55% by 2025 for household waste (including compostable waste), 70% by 2020 for construction and demolition waste and 60% by 2025 for plastic packaging, for all member states (European Commission 11/19/2008; Goodship, 2012; European Commission 5/30/2018) (S. Wagner & Schlummer, 2020). In the UK these targets are devolved to the four nations.Waste Electrical and Electronic Equipment Regulations The Waste Electrical and Electronic Equipment Regulations 2013 (as amended) transpose the main provisions of Directive 2012/19/EU on WEEE. In Great Britain and Northern Ireland, the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 (as amended) are the underpinning legislation. The Regulations aim to reduce the amount of WEEE going to landfill, by requiring all manufacturers and producers to take responsibility for what happens to the products they sell at end of life.

There are six broad categories of WEEE currently outlined within the regulations, namely: large/small EEE equipment, small information technology and telecommunication equipment, screens/monitors.

Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations In Great Britain and Northern Ireland, the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012 (as amended) are the underpinning legislation The Regulationsaim to prevent the risks posed to human health and the environment related to the management of electronic and electrical waste The Regulations restrict (with exemptions) certain hazardous substances in EEE that can be substituted by safer alternatives. More specifically, the the use of ten substances: lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP) (European Commission, 2011). These substances should not exceed maximum concentration values (MCV) of 0.1% (tolerated by weight) in EEEs, or 0.01% by weight in the case of cadmium compounds.

1.1.1.19 **UK REACH Regulation.**

The REACH regulation was adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry (ECHA, 2021).

REACH demands physicochemical, toxicological and ecotoxicological data for each chemical with an annual production or trading quantity exceeding 1 tonne (S. Wagner & Schlummer, 2020). To comply with the regulation, businesses must identify and manage the risks linked to the substances they manufacture and market in the EU. Businesses have to demonstrate to the Health and Satefy Executive (HSE) how the substance can be safely used, and they must communicate the risk management measures to the users

According to the UK REACH regulation substances of Very High Concern (SVHC) include substances which are:

- Carcinogenic, Mutagenic or toxic to Reproduction (CMR)
- Persistent, Bioaccumulative and Toxic (PBT) or very Persistent and very Bioaccumulative (vPvB)
- Identified, on a case-by-case basis, from scientific evidence as causing probable serious effects to human health or the environment of an equivalent level of concern as those above (e.g. endocrine disrupters).

1.1.1.20 **CLP Regulation**

The classification, labelling and packaging of chemicals placed on the market in Great Britain (England, Scotland and Wales) is regulated by the 'Retained CLP Regulation (EU) No. 1272/2008 as amended for Great Britain'. This is based on the United Nations' Globally Harmonised System (GHS) and its purpose is to ensure a high level of protection of health and the environment, as well as the free movement of substances, mixtures and articles .

The Regulation requires manufacturers, importers or downstream users of substances or mixtures to classify, label and package their hazardous chemicals appropriately before placing them on the market. Although CLP is a separate legislation, the information it generates is part of REACH registration.

1.1.1.21 **POP Regulation**

Persistent organic pollutants (POPs) are chemicals that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. POPs consists of: pesticides (such as DDT [Dichlorodiphenyltrichloroethane]), industrial chemicals (such as polychlorinated biphenyls, PCBs) and unintentional by-products of industrial processes (such as dioxins and furans).The POP Regulation bans or restricts the use of persistent organic pollutants in both chemical products and articles (European Commission, 2021a). Any POP-containing substances must be disposed of correctly. If a material, waste or piece of equipment has a POP concentration **at or above the thresholds** stated in the POPs Regulation, it must dispose of it in accordance with the regulations, for example, by physico-chemical treatment or incineration. There is also a need to assess if the POP or POP-containing substance or equipment is classed as hazardous/special waste. This will place additional requirements on how you store, transport and dispose of such substances (The Persistent Organic Pollutants (Amendment) (EU Exit) Regulations 2020).

1.1.1.22 Product-specific legislation

Any business that makes, imports, distributes or sells products within the UK must comply with the regulations for specific product types. If no specific product type regulation applies, the business must comply with the General Product Safety Regulations 2005.

Table 24 details a summary of applicable regulations that can apply for each product group:

Table 24: Applicable regulations by product group

Product Group	Applicable Regulations
Childcare articles and children's equipment	The N-nitrosamines and N-nitrosatable Substances in Elastomer or Rubber Teats and Dummies (Safety) Regulations 1995 These Regulations apply to teats and soothers (referred to as "dummies" in these Regulations) intended to be (or which are) brought into contact with foodstuffs. The Regulations provide that the supply of a teat or dummy not complying with their requirements is prohibited
Clothing, textiles and fashion items	The Nightwear (Safety) Regulations 1985 The Nightwear (Safety) Regulations 1985 make it an offence to supply some children's nightwear unless it has been treated so that it conforms, after washing, to the flammability performance requirements of British Standard BS 5722: *Specification for flammability performance of fabrics and fabric assemblies used in sleepwear and dressing gowns*. The Regulations lay down labelling requirements so that purchasers can tell whether other nightwear - including adults' - meets the flammability requirements.
Cosmetics	Cosmetic Products Enforcement Regulations 2013 The Regulations apply to all cosmetic products that are made available on the EU market after 11 July 2013. It is an offence to supply cosmetic products which may cause damage to human health when applied under normal or reasonably foreseeable conditions of use.
Electrical appliances and equipment	Electrical Equipment (Safety) Regulations 2016 These regulations set out the requirements that must be met before electrical equipment products can be placed on the GB market.
	Electrical Equipment (Safety) Regulations 1994 – These regulations were revoked on 8 December 2016 but continue to apply to relevant products placed on the market prior to this date.
	Electromagnetic Compatibility Regulations 2016
	Electromagnetic Compatibility Regulations 2006 – These regulations were revoked on 8 December 2016 but continue to apply to relevant products placed on the market or put into service prior to this date.
	Radio Equipment Regulations 2017

	Radio Equipment and Telecommunications Terminal Equipment Regulations 2000 – These regulations were revoked on 26 December 2017 but continue to apply to relevant products placed on the market prior to this date.
	The Plugs and Sockets (Safety) etc. Regulations 1994 These regulations require that domestic mains powered appliances are fitted with a standard plug conforming to BS 1363
Toys	· Toy (Safety) Regulations 2011 The 2011 Regulations set out the essential safety requirements that must be met before toys can be placed on the GB market. The purpose of the legislation is to ensure safe products are placed on the market by requiring manufacturers to show how their toys meet the 'essential safety requirements'
Furniture	· The Furniture and Furnishings (Fire) (Safety) Regulations 1988 The Furniture and Furnishings (Fire Safety) Regulations 1988 (as amended in 1989, 1993 and 2010) set levels of fire resistance for domestic upholstered furniture, furnishings and other products containing upholstery.

(Office for Product Safety and Standards, 2021)

International Standards

1.1.1.23 Overview and key organisations

Standards play an important role in the regulation of consumer safety in the UK. The government often draws on standards when putting together legislation or guidance documents. Standards are used to establish the technical detail, allowing the legislation to concentrate on broad essential requirements for products or long term policy objectives, such as product safety, or environmental protection. Compliance with the standard will mean compliance with the relevant legislation, although there are usually ways of being compliant with legislation without using a standard (BSI, 2021b).

There are three key organisations which initiate, publish and maintain standards:

British Standards (BS): National standards specify the requirements for application in the particular country. British Standard – BS denotes Britain's National Standards which are controlled by the British Standards Institute (BSI). BSI is appointed by the UK Government as the national standards body. This leads BSI to seek wherever possible to develop international standards first, maximizing the UK stakeholders' significant influence on market access conditions globally. European regional standards are developed where there are no international standards or where there are specific interests in the region that could not be addressed globally.

International and European standards are adopted for the whole of the UK as British Standards, alongside a diminishing proportion of national-only standards that meet purely local needs. These national standards are often developed as precursors to international work and are transferred into international processes in due course.

European Committee for Standardisation (CEN): EN denotes a Standard which is adopted by the European community and is controlled by the European Committee for Standardisation (CEN). European standards are aimed at facilitating commerce between the countries of the European community and they enable cooperation between the different national standards. The standards are voluntary but can be very relevant to prove compliance of a product. Products compliant with a standard referenced in the European Union Official Journal are presumed to be compliant.

Some categories of products are covered by product specific legislation such as toys, electrical appliances, cars etc. Products for which there is no product specific legislation fall under the general product safety directive. This is the case, for example, for most childcare articles (European Commission, 2021b).

Once a European Standard has been agreed it supersedes any existing national standard and becomes the new national standard. In Britain these Standards are then prefixed with BS EN.

International Organisation for Standardisation (ISO): ISO denotes a worldwide standard issued by the International Organisation for Standardisation. Once an International Standard has been adopted as a European Standard it supersedes the existing European standard. In Britain these Standards are then prefixed with BS EN ISO, e.g. "BS EN ISO/IEC 17020: 2004 General criteria for the operation of various types of bodies performing inspection". This superseded EN 45004:1995. For electronics, **International Electrotechnical Commission (IEC)** standards are relevant, with many electrical safety standards being BS EN IECs.

Analysis of relevant standards

1.1.1.24 Methodology

The following section details a summary of applicable standards for each product group. As BSI is appointed by the UK Government as the national standards body, the BSI Standards Development Portal was used to obtain a list of all the published standards relating to each product group.

The British Standards Development search function[6] was used to search for and narrow down relevant standards for each product category and chemical group. Firstly, the categories already sorted on the website were initially used, such as “Commercial and Consumer Goods > Furniture” and “Commercial and Consumer Goods > Equipment for children”. All available standards for that category were then downloaded and sorted through manually. The criteria used to narrow these down to potentially relevant ones was the inclusion of any mention of ‘chemical’, ‘hazardous’, ‘recycling’, ‘recycled’, or any of the specific chemicals of interest in the title. The built-in categories for electrical items were very broad, so specific searches for products based on the most commonly cited products found in the literature review was done. Based on products identified most regularly in the literature review (see 2.1) and Safety Gate analysis (see 2.3), the products searched for were: television, refrigerator, keyboard, computer mouse, computer monitor, computer screen, rice cooker, microwave oven, printer. The resulting standards were then narrowed down as above. This was repeated but with specific searches for individual chemicals of interest: phthalate, brominated flame retardant, BFR, chlorinated flame retardant, CFR, bisphenol, formaldehyde, persistent organic pollutant, POP, heavy metal and paraben. The standards found were then narrowed down based on their relevance to the product groups of interest. This resulted in a full list of 2198 standards, 114 of which were highlighted as potentially relevant. All standards highlighted as of interest were then searched for specifically in the literature for information on their content and relevance. They were not all read in full due to access limitations and so the information on some is taken from sources other than the standard itself. A

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[6] *https://standardsdevelopment.bsigroup.com/*

breakdown of the standards judged potentially relevant can be found in the Technical Annex.

The second method used for searching of standards was searching literature. Some sources that had been used for the literature review contained information on standards or mentioned specific standards (e.g. Okeo-Tex Standard 100 which was mentioned several times in literature sources), so these were then searched for on the appropriate standards body or company website for further information.

At EU level, European Committee for Standardisation (CEN) standards have been set and are used to characterise plastic materials at the secondary raw material stage as regranulates, flakes or pellets (i.e. after plastic products have been reprocessed, but before they are manufactured into a new product). These EU standards define quality requirements, relevant test protocols and limit values for each parameter. The EN standards for plastics recyclate which define tests for generic characteristics are shown in Table 25 (Villanueva & Eder, 2014).

Table 25: Common standards used for recyclates in the EU

Standard	Description
EN 15342, 2007	Plastics - Recycled Plastics - Characterization of polystyrene (PS) Recyclates
EN 15343, 2008	Plastics - Recycled Plastics - Plastics recycling Traceability and Assessment of Conformity and Recycled Content
EN 15344, 2008	Plastics - Recycled Plastics - Characterisation of Polyethylene (PE) Recyclates
EN 15345, 2008	Plastics - Recycled Plastics - Characterisation of Polypropylene (PP) Recyclates
EN 15346, 2014	Plastics - Recycled Plastics - Characterisation of poly(vinyl chlorode) (PVC) Recyclates
EN 15347, 2008	Plastics - Recycled Plastics - Characterisation of Plastics Wastes
EN 15348, 2014	Plastics - Recycled Plastics - Characterisation of poly(ethylene terephthalate) (PET) Recyclates

Standards EN 15342, EN 15344, EN 15345, EN 15346 and EN 15348 describe the most important characteristics and test methods to assess PS, polyethylene (PE), PP, PVC and PET recyclates intended for use in the production of other products. However, these standards are generic and open for contaminants (Knapp et al., 2017) as characteristics of the recyclate can either be mandatory (required for all recyclates) or optional (according to customer requirements). Standard EN 15343 describes a framework for ensuring traceability in recycled materials by outlining the necessary procedures required for products that have been manufactured completely or partly from recycled materials. The required procedures for traceability include: control of input material, plastics recyclate characterisation, and traceability (including description of origins, logistics, tests carried out before processing, processing parameters, post-processing testing and intended application).

Tests required by the standards can be performed at the output stage of the reprocessing step as well as at the final product. Reprocessors are usually responsible for ensuring the quality of the recyclate produced. However, the standards are generic in terms of contaminant content, and quality is often negotiated between material provider and buyer when not required by legislation (Villanueva & Eder, 2014).

There are also standards in place for the chemical safety of specific product groups, and although these are not often specific to recycled products or products likely to be recycled, such products can also follow these standards for best practise or to meet legislative requirements.

1.1.1.24.1 Textiles

There are several standards that outline laboratory test methods for the determination of hazardous compounds in textiles for regulatory compliance. Standards covering chemicals of interest for this report are presented in Table 26.

Table 26: Standards relating to hazardous chemicals in textiles

Standard	Description	Chemical(s)
BS EN ISO 14184-1:2011	Determination of formaldehyde — Part 1: Free and hydrolysed formaldehyde (water extraction method)	Formaldehyde
BS EN ISO 14184-2:2011	Textiles. Determination of formaldehyde. Released formaldehyde (vapour absorption method)	Formaldehyde
BS 6810-2:2005	Determination of metals in textiles. Analysis by atomic emission spectroscopy	Metals
BS EN 17132:2019	Textiles and textile products. Determination of Polycyclic Aromatic Hydrocarbons (PAH), method using gas chromatography	PAHs
BS EN ISO 17881-1:2016	Textiles. Determination of certain flame retardants. Brominated flame retardants	BFRs
BS EN ISO 17881-2:2016	Textiles. Determination of certain flame retardants. Phosphorus flame retardants	PFRs
ISO/TR 17881-3:2018	Textiles — Determination of certain flame retardants — Part 3: Chlorinated paraffin flame retardants	SCCPs (FRs)
DD CEN ISO/TS 16181:2011	Footwear. Critical substances potentially present in footwear and footwear components. Determination of phthalates in footwear materials	Phthalates

There are also standards which provide certification or labels that regulatory and/or additional requirements have been met. These includes STANDARD 100 by OEKO-TEX®, the BlueSign Standard and the TOXPROOF standard by TÜV Rheinland.

STANDARD 100 by OEKO-TEX® provides a standard on harmful substance testing in textiles, with the label meaning consumers can be certain that every component of an article has been tested for harmful substances and is therefore safe for human health. The limit values for substances under STANDARD 100 often go beyond national and international requirements. It takes into account numerous regulated and non-regulated substances including substances of interest for this review: formaldehyde (limit of 16-150 mg/kg depending on use), heavy metals including Sb

(30 mg/kg), Arsenic (As) (0.2 mg/kg), Pb (0.2 mg/kg), Cd (0.1 mg/kg) and Cr (1.0 mg/kg), phthalates (0.025 wt %), BPA (100 mg/kg), PAHs (∑

24 PAHs 5-10 mg/kg), perfluorinated compounds including PFOS (1.0 mg/kg) and PFOA (0.025 mg/kg), as well as flame retardants including PentaBDE and DecaBDE (forbidden) (Oeko-Tex, 2021b, 2021c). STANDARD 100 has special requirements for recycled products – only post- and pre-consumer waste material may have been used in the manufacturing of the product and proof indicating the recycled origin must be submitted. A higher testing frequency may also be applicable depending on the origin of the material (Oeko-Tex, 2021a).

The BlueSign Standard is a standard in the manufacturing of textiles, cutting out harmful chemicals in the manufacturing process for the health of the environment, the workers and customers. It follows 5 principles: resource productivity, consumer safety, water emissions, air emissions and occupational health and safety. The scope of an approved bluesign® PRODUCT includes footwear, toys and furniture (bluesign, 2020a). The standard categorises chemicals into banned and limited. Formaldehyde is limited, with concentrations limits of 15-300 mg/kg depending on end use (lower for next to skin use and baby articles, higher for no skin contact applications). Some heavy metals (including their salts and compounds) are also limited or have usage bans including: antimony (5-10 mg/kg extractable metal content limit in textiles), arsenic (10 mg/kg), barium (100 mg/kg), cadmium (0.1 mg/kg), chromium (0.5 mg/kg), cobalt (1.0 mg/kg), copper (25-50 mg/kg), lead (0.2-1.0 mg/kg), mercury (0.02 mg/kg), nickel (1.0 mg/kg) and selenium (500 mg/kg). Bisphenol A has a usage ban and limit of 1.0 mg/kg in textiles. Bisphenol S has a monitoring limit where the amount must be reported, with a limit of 10 mg/kg. A wide range of perfluorinated substances including PFOA, PFAS and PFBS have a series of monitoring limits and usage bans. HBCDD (flame retardant) has a usage ban, as well as PBDEs, although there is also a 5.0 mg/kg limit on most. A range of phthalates including butylbenzyl phthalate, dimethyl phthalate and dibutyl phthalate have a usage ban and limit of 50 mg/kg. The standard provides test methods for quantifying each substance in materials (bluesign, 2020b) but does not discuss recycling.

The TOXPROOF standard by TÜV Rheinland certifies whether textile products including home textiles, mattresses, clothes and floor coverings contain toxins that are a risk to our health (TÜV Rheinland, 2021). The test covers all known, potentially harmful substances, possible contamination, and the materials used to preserve the product during shipment and storage. Test conditions are chosen depending on how consumers are likely to use the product, ensuring reliable results. Chemicals of interest that are tested for include formaldehyde and heavy metals, including a 1.0 mg/kg Sb limit (Rovira & Domingo, 2019).

1.1.1.24.2 **Electronics**

There are several relatively well-established global standards for the reporting and communication of hazardous substances in electronics including the JIG-101, IEC 62474 and IPC-1752A.

The Joint Industry Guide (JIG) standard JIG-101 is a material declaration standard developed by and for the global electronics industry (Consumer Electronics Association, 2011). It is a communication tool for manufacturers in the electronics industry and applies to both products and subparts. The standard aims to facilitate the reporting of material content and lists materials and substances that are subject to regulatory or market requirements which must be disclosed and those that have threshold levels. The standard also states that material composition information required can help manufacturers to respond to inquiries from product recyclers.

Chemicals included in the standard includes BFRs (other than PBBs, PBDEs, or HBCDD) (with a limit of 0.1 wt%), formaldehyde, HBCDD (0.1 wt%), PFOS (0.1 wt%), phthalates including DEHP (0.1 wt%), DBP (0.1 wt%), BBP (0.1 wt%) and DIBP (0.1 wt%), PBDEs (0.1 wt%), PCBs and PBBs (0.1 wt%). Heavy metals are also limited: cadmium (0.01 wt%), chromium VI (0.1 wt%), lead (0.1 wt% or 0.03 wt% for products for children under 12 years old and cables with thermoset coatings), mercury (0.1 %) and nickel (Consumer Electronics Association, 2011).

In 2014, the JIG-101 list was replaced by the International Electrotechnical Commission (IEC) 62474 Material Declaration Standard. The standard is used globally within the electronics industry to demonstrate compliance with various environmental regulations (IEC, 2021). It provides a framework for the exchange of information on material composition and assists companies in determining whether the concentration level of any restricted substance in their product exceeds the reporting threshold. Declarable substances in this standard includes phthalates (DEHP, DBP, BBP, DIBP, Diisodecyl phthalate (DIDP), DINP, DNOP at a limit of 0.1 wt%), HBCDD (0.01 wt%), PBDEs (0.1 wt%), PBB (0.1 wt%), PCBs, CFRs (0.1 wt%), PFOA (0.1 wt%), PFOS and heavy metals including cadmium, chromium, lead, mercury and nickel (IEC, 2021). In 2018 a new edition of the standard linking forward logistics to reverse logistics relating to the reuse and recycling of products and materials. IEC 62321 provides a framework of testing for the determination of certain substances in electronic products, including heavy metals, phthalates, HBCDD and PAHs (IEC, 2013).

The IPC-175x family of standards are also supplier declaration standards used by the electronics industry to communicate information on substances and material composition throughout the supply chain. This information can then be used by down-stream manufacturers to assess materials and parts for regulatory compliance. IPC-1752A specifically concerns EEE (IPC, 2014). Initially, the IPC list of reportable substances focused on RoHS guidelines and other substances viewed as potential health and/or environmental risks. The JIG-101 list went through several updates before it was discontinued in the latest IPC-1752A standard. The reportable list is now based on the IEC 62474 database. Since IEC 62474 is also a reporting protocol, bodies are working towards harmonising the IPC and IEC standards to have one combined protocol and reportable substance list.

111/610/NP , PNW 111-610 ED1 Sustainable management of waste electrical and electronic equipment (e-waste) is currently in the proposal stage, however it specifies the requirements for the sustainable management of WEEE to ensure the protection of human health and safety and of the environment. It provides a framework for assuring customers and other stakeholders of the safety quality of the material, preparing for re-use and of recycling operations (BSI, 2021a). Although this standard is not yet complete or published, it highlights the growing awareness of WEEE recycling and its health and environmental implications in terms of toxic and hazardous substances.

EN 50574:2012 and BS EN 50625-2-3:2017 cover the collection, logistics and treatment requirements for end-of-life household appliances and temperature exchange equipment and other WEEE respectively containing volatile fluorocarbons or volatile hydrocarbons (CENELEC, 2012, 2014).

Some electronics manufacturers have produced standards themselves to govern the toxic substances in their products. IBM developed the “Baseline Environmental Requirements for Materials, Parts and Products for IBM Logo Hardware Products” which bans decaBDE content, and HP use the “Hewlett-Packard's environmental standard: General Specification for the Environment (GSE)" which limits PBDE content (Keet et al., 2011).

Other standards that are relevant to the environmental assessment of electronic products include IEEE 1680-2009 (IEEE SA, 2009) and EPEAT (US EPA, 2014).

These standards may be relevant to recycled products or products that may be recycled but are not specific to this. However, there are other standards such as SGS's globally recognised Responsible Recycling© Standard (R2) certification that do specifically cover hazardous substances in electronics recycling (SERI, 2013). This standard provides a framework for recycling management and EHS management systems. Substances covered by the standard are mercury and PCBs, meaning the standard is less exhaustive in terms of chemicals than more generic standards such as IEC 62474, but the standard also covers safe transport, disposal, storage and worker safety.

The e-Stewards® Standard for Ethical and Responsible Reuse, Recycling, and Disposition of Electronic Equipment and Information Technology is another standard specific to electronics disposal, recycling and reuse. It was introduced in 2009 to promote conformity with the Basel Convention in the electronics recycling industry. This standard includes guidance on PCBs, BFRs and metals (arsenic, barium, beryllium, cadmium, chromium, lead, mercury and selenium) (e-Stewards, 2020).

1.1.1.24.3 **Toys and childcare articles**

The BS EN 71 standard series specifies safety requirements for toys. Compliance with the essential requirements of the European Toy Safety Directive is legally required for all toys sold in the EU, and BS EN 71 compliance is a primary means of demonstrating that those requirements are met. Many of these correlate with international standards such as ISO 8124-3 (Safety of toys. Part 3: Migration of certain elements) and ISO 8124-6 (Safety of toys. Part 6: Certain phthalate esters in toys and children's products). The standard is aligned with both ISO 8124 and ASTM F963, although ASTM F963-11 contains additional CPSIA (Consumer Product Safety Improvement Act) requirements on total Pb and soluble Cd content (Guney et al., 2020).

BS EN 71-3:2019+A1:2021 standard contains guidelines to assess the migration of certain chemicals found in toys into the body, specifically if a toy or components of a toy were to be swallowed by a child. There are 3 different categories of toy covered by the standard, but plastics are in the one with the most lenient limits as the risk of ingestion is assumed to be lower. In 2019, BS EN 71-3:2019 was published which specifies requirements and tests for the migration of heavy metals and toxic elements such as aluminium (70,000 mg/kg limit), antimony (560 mg/kg), arsenic (47 mg/kg), barium (18,750 mg/kg), boron (15,000 mg/kg), cadmium (17 mg/kg), Chromium (III) (460 mg/kg), Chromium (VI) (0.053 mg/kg), cobalt (130 mg/kg), copper (7,700 mg/kg), lead (23 mg/kg), manganese (Mn) (15,000 mg/kg), mercury (94 mg/kg), nickel (930 mg/kg), selenium (460 mg/kg), strontium (56,000 mg/kg), tin (180,000 mg/kg), organic tin (12 mg/kg) and zinc (46,000 mg/kg) (BSI, 2019). These limits are harmonised with the Toy Safety Directive 2009/48/EC.

BS EN 71-9:2005+A1:2007 specifies requirements for organic chemical compounds in EU toys including solvents, preservatives, plasticisers, flame retardants, monomers, biocides, processing aids and colouring agents. It also specifically covers formaldehyde. The tests specified depends on the specific toy or toy component, with most plastic toys only tested for monomers, solvents and plasticisers (TÜV SÜD

Greater China, 2019). Sample preparation for these tests is found in BS EN 71-10:2005 and BS EN 71-11:2005 covers methods of analysis.

Other standards cover specific products such as cutlery or drinking equipment which may require stricter limits due to their increased skin contact. Examples of these are EN 14372 and EN 14350:2010. EN 14372 covers cutlery and feeding utensils in the child use and care articles standards. Depending on plastic type, the standard covers tests for heavy metals including Sb (15 mg/kg limit), As (10 mg/kg), Barium (Ba) (100 mg/kg), Cd (20 mg/kg), Pb (25 mg/kg), Cr (10 mg/kg), Hg (10 mg/kg) and Selenium (Se) (100 mg/kg), phthalates (0.1 wt% limit), formaldehyde (15 mg/kg migration liquid), nickel and BPA (0.03 µg/mL aqueous food stimulant) (CEN, 2004). EN 14350:2020 covers drinking equipment for young children and covers BPA and phthalates in addition to heavy metals. EN 1400:2013 and EN 12586 cover heavy metal content, formaldehyde, BPA and phthalates in soothers/pacifiers and their holders (SGS, 2015).

The standards for toys and childcare articles appear to be relatively harmonised with the regulations. This is likely to be due to the strict regulations surrounding children's products and the nature of their regular contact with skin and saliva.

1.1.1.24.4 **Motor Vehicles**

The BS ISO 12219 standard series provides information on testing for volatile and semi-volatile organic carbon compounds, formaldehyde and other carbonyl compound emissions from vehicle interior parts and materials (BSI, 2012). These are presented in Table 27.

Table 27: Standards relating to determining VOC emissions in car interiors

Standard	Description
BS ISO 12219-1:2012	Indoor air of road vehicles. Whole vehicle test chamber. Specification and method for the determination of volatile organic compounds in cabin interiors
BS ISO 12219-2:2012	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Bag method
BS ISO 12219-3:2012	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Micro-scale chamber method
BS ISO 12219-4:2013	Interior air of road vehicles. Method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Small chamber method
BS ISO 12219-5:2014	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Static chamber method
BS ISO 12219-6:201	Interior air of road vehicles. Method for the determination of the emissions of semi-volatile organic compounds from vehicle interior parts and materials at higher temperature. Small chamber method
BS ISO 12219-9:2019	Interior air of road vehicles. Determination of the emissions of volatile organic compounds from vehicle interior parts. Large bag method

PD CEN/TS 17045:2020 (Materials obtained from end-of-life tyres. Quality criteria for the selection of whole tyres, for recovery and recycling processes) provides criteria for the sorting of whole end-of-life tyres as well as criteria for determining their suitability for recycling (BSI, 2020).

1.1.1.24.5 **Furniture**

The majority of safety standards found relating to furniture were regarding physical safety, strength and flammability. There are also strict regulations on chemicals such as flame retardants (Furniture and Furnishings (Fire Safety) Regulations 1988) due to the risk of fire in homes and offices. No standards were found relating to hazardous substances in furniture specifically, but many of the textile standards also apply to upholstered furniture. For example, the TOXPROOF standard by TÜV Rheinland covers home textiles, mattresses and floor coverings as well as clothing (TÜV Rheinland, 2021). Home textiles and decorative materials are also covered by OEKO-TEX® STANDARD 100; the Product Class 4 covers all articles used for furnishing purposes such as table cloths, mattresses, curtains and upholstery fabrics. STANDARD 100 has special requirements for recycled products – only post- and pre-consumer waste material may have been used in the manufacturing of the product and proof indicating the recycled origin must be submitted. A higher testing frequency may also be applicable depending on the origin of the material (Oeko-Tex, 2021a).

1.1.1.24.6 **Cosmetic Packaging**

The majority of standards found relating to cosmetic packaging was with regards to correct labelling (BS ISO 22715:2006). Other standards that came up in relation to hazardous substances were for within the cosmetic itself rather than the packaging (BS EN 16521:2014 and PD ISO/TR 17276:2014).

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Review of EU Safety Gate

An analysis of product reports on the EU Safety Gate portal[7] was undertaken as a supplement to the literature review. Safety Gate is the EU's 'rapid alert system for dangerous non-food products'. It was formerly known as RAPEX. Under the Safety Gate system, member states of the EU and European Economic Area (EEA) and the European Commission can exchange information on non-food products on their market which may pose a serious risk to the health and safety of consumers, allowing the products to be withdrawn or safety notices issued.

There is no distinction within Safety Gate about the origin of the product materials which might indicate contamination by recycling or not. This stage of the scoping study was therefore not believed to directly answer the research questions in relation to recycling. However, as a substantial data source of chemical hazards in consumer items, a quick overview of its contents gives an indication into the type of chemical hazards regularly reported in the EU which may be instructive when compared to the issues raised in the literature on recycled products. Despite its limitations, therefore, analysis of Safety Gate contributes as part of the wider scoping study in conjunction with other sources of information, providing possible indications for areas of future research.

A summary of the results is presented in section 2.3.1. This is followed by more detail of the method (section 2.3.2) and detailed results by product group and analyte (section 2.3.3),

Summary

Analysis of the Safety Gate data took all chemical hazard alerts published on the system since 2005. This data was analysed with focus on two different datasets: one based on alerts with detailed product information (n=3,983) used to examine if specific product types had greater documented chemical risk than others; the second dataset based on safety alerts with extra information about the type of chemical risk (n=2,190), including reference to particular analytes, in order to analyse whether particular chemical groups were more regularly identified than others.

The two most abundant product categories were toys and clothing and textile items. These accounted for 95% of total alerts (72% and 24% respectively). This suggests that these groups present the greatest chemical safety concern. However, it may also reflect relative numbers of items on the market, or biases in enforcement if these products are tested more regularly than others. The particularly high share of alerts for toys (72%) suggests there may be a risk of toxic chemical presence in toys.

Within these product categories, certain types of product stood out: dolls and non-figurine toys, made primarily of hard and soft plastics, made up to 71% of all toy-related alerts. Footwear and accessories accounted for 69% of clothing alerts.

Safety alerts were raised overwhelmingly for products originating outside of the EU: more than 90% of both toy and clothing alerts originated in non-EU countries, with China being particularly important for toy manufacturing.

[7] https://ec.europa.eu/safety-gate-alerts/screen/webReport

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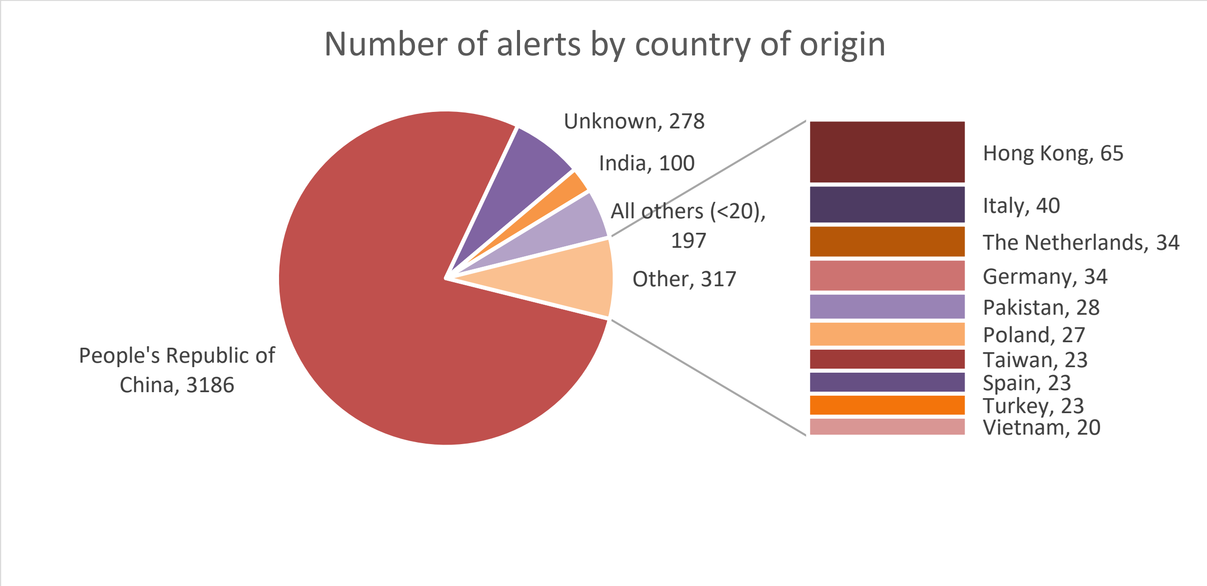

Figure 4: Safety Gate alerts (all products) by country of origin

Of the analyte groups in scope, only four were documented as being present across the Safety Gate dataset: phthalates, heavy metals, flame retardants and formaldehydes, which were mentioned in 76%, 22%, 14% and 2% of alerts respectively. Other POPs, perfluorinated chemicals, parabens and bisphenols were not mentioned in any of the alerts identified.

Phthalates were found overwhelmingly in the toys category, with heavy metals identified across both toys and clothing alerts. When combined with information on the product group and origin, the data suggests that phthalates are being used purposefully but at scales in contravention of content limits. This suggests that there may be particular issues related to the use of phthalates at high concentrations in Chinese manufactured toys. This conclusion is caveated by being a known issue, which may be disproportionately targeted by regulators, leading to more safety alerts.

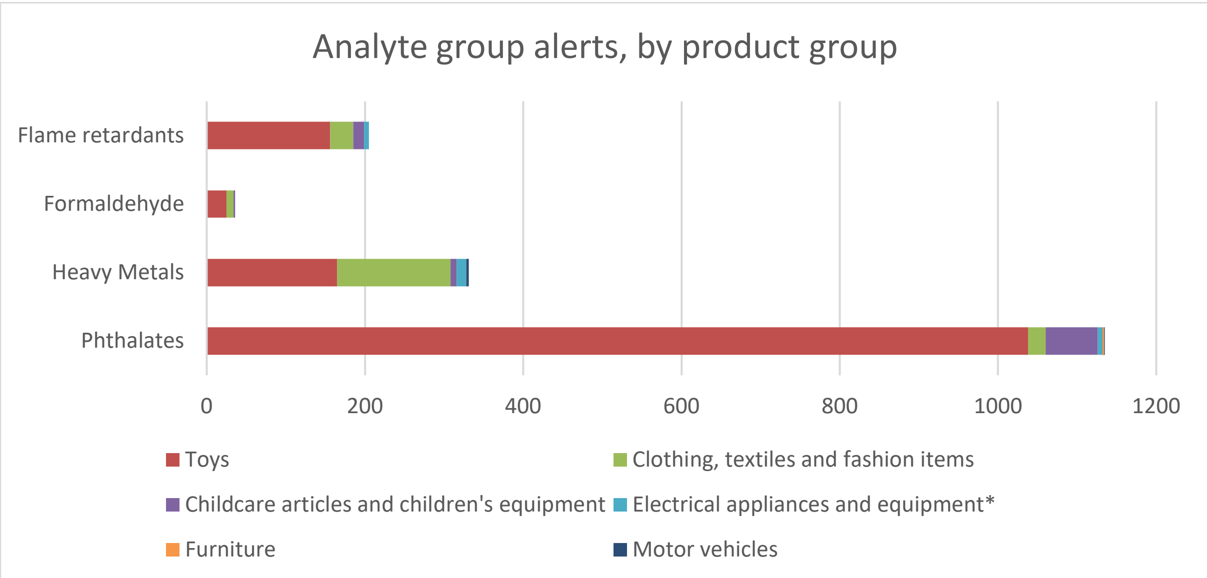

Figure 5: Chemical alerts by analyte and product group

The information from Safety Gate crucially does *not* tell us anything about the role of recycling as a possible source for contamination of these products. However, this overview should demonstrate that, in terms of number of products which may exceed legal limits of toxic chemicals, toys and clothing are the product groups of the most concern. Overwhelmingly, alerts are raised on products in these groups which are imported from outside the EU*[8]. Imported goods, rather than domestic industry, appears to be the driver of chemical hazards. The most recurring issues were those of phthalates in toys and heavy metals in clothing. In both these cases, it is suggested that the source is purposeful addition but in illegally high levels, rather than being driven by contamination through recycling or any other contamination route.

Method

The Safety Gate portal (formerly RAPEX) documents each individual product submitted by member states. As these alerts reach the thousands, a quantitative analysis was undertaken: all chemical safety alerts from every year available (2005-2021) were downloaded.

The data was extracted in March 2021. The results from this search, by product group, are displayed in Table 28. More detail of the method, including how data was transformed, can be found in the Technical Annex.

Table 28: Safety Gate product alerts by product category

Category	Number of alerts
Toys	2907
Clothing, textiles and fashion items	1001
Childcare articles and children's equipment	117
Electrical appliances and equipment	32
Motor vehicles	13
Furniture	8
Cosmetics	2048
Total	6126

This shows that by some distance the product groups with the most alerts raised are toys, clothes and cosmetics.

Cosmetics were excluded from the main dataset due to the focus of this review being possible risks from recycled content, which would be regarding cosmetic packaging, rather than chemicals introduced to the cosmetic substance. The basis for exclusion is detailed further in the Technical Annex, alongside an analysis of the cosmetics alerts in isolation. All future analysis applies only to the dataset listed in Table 28 but not containing cosmetics, in which the final number of alerts was 4,078.

1.1.1.25 Limitations of the Safety Gate data format

Product reports on Safety Gate are not conducive to quantitative analysis of thousands of results. Many of the fields, most notably the two variables of primary interest: ‘product’ and ‘risk’ appear to allow for free-text entry of submissions. As a result, there is a very low level of standardisation in responses. As a result, even in the alerts with data in the ‘product’ and ‘risk’ fields, additional stages were required to

[8] *For the purposes of this analysis, EU* is used to designate the EU, UK and Switzerland.*

group these, and these efforts will likely have overlooked some responses due to spelling variation, different terminology and so on. The data transformation undertaken to prepare the data is detailed in the Technical Annex. The uncertainties and inaccuracies which may have arisen from these formatting issues mean the results are caveated as being possibly imprecise, offering only an indicative view.

Results

Below presents descriptive statistics relating to the data available from the Safety Gate portal. When discounting product alerts which did not enter data into the fields analysed ('Product' and 'Risk'), two very different samples emerge based on the field of interest. To avoid confusion, the two analyses are presented in separate sub-sections. Firstly, however, some descriptive statistics from the overall dataset.

1.1.1.26 **Whole dataset**

Over the entire dataset, 4,078 alerts were identified. These split across the product categories is detailed in Table 29:

Table 29: Safety Gate product alerts by product category, final dataset

Category	Number of alerts	Share of alerts
Toys	2907	71%
Clothing, textiles and fashion items	1001	25%
Childcare articles and children's equipment	117	3%
Electrical appliances and equipment	32	0.78%
Motor vehicles	13	0.32%
Furniture	8	0.20%

Toys are disproportionately represented in the Safety Gate data. There are three key reasons which may drive this: firstly, it may reflect the number of products which could possibly have a toxic alert. Things like electronics and furniture typically represent more expensive items which a household would have a small number of, the inverse is true for toys which are usually relatively cheap and ubiquitous. Secondly, it may be a result of stricter restrictions on chemical contents in toys due to children being the target audience. Lastly, it could reflect a genuine increased relative use of toxic materials in those products. The overrepresentation of toys is discussed more in section 2.3.4.

Safety Gate documents the country of origin of product alerts. 78% of these are listed as China, which is by some distance the largest origin country. Just 12 known countries of origin had more than 20 product alerts identified, these are displayed in Figure 6.

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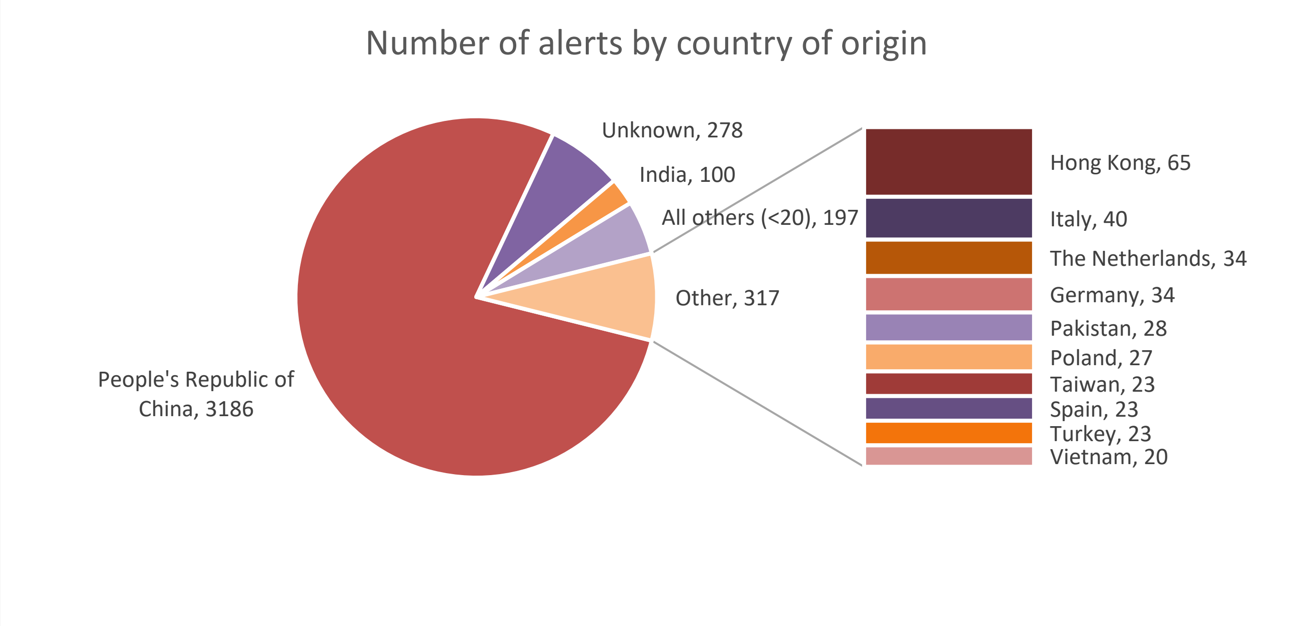

Figure 6: Safety Gate alerts (all products) by country of origin

It is notable that alongside the People's Republic of China, Hong Kong and Taiwan appear amongst the most frequent origin countries, and we can assume that some share of the unknown origin products come from China. Chinese-origin products are clearly of particular chemical concern. However, as is shown in Table 30, its role as an origin source is unevenly distributed across the product categories:

Table 30: Alerts with China as origin country, by product category

Category	Total number of alerts	Share with China as origin country
Toys	2907	88%
Clothing, textiles and fashion items	1001	54%
Childcare articles and children's equipment	117	48%
Electrical appliances and equipment	32	75%
Motor vehicles	13	31%
Furniture	8	100%

However, this does not necessarily mean that a greater *share* of Chinese production has chemical risks associated with it. It may rather reflect China's position as the world's major producer of consumer goods. Some estimates suggest that about 70% of the world's toys are manufactured in China, meaning its presence as the most significant origin country for toys with alerts is likely to be expected (S.-J. Chen et al., 2009).

Only 1.2% of alerts were known to be counterfeit products. However, 49.4% were classified as 'unknown', so it could be possible that a larger share of safety alerts came from counterfeit products.

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The dataset only included those listed on Safety Gate as having a chemical risk. However, a non-negligible number, approximately 9%, were also documented as having an additional, non-human-chemical risk such as choking, strangulation or environmental damage.

1.1.1.27 **Product groups**

The product alert dataset was filtered to all available alerts which had information pertaining to the product that had not been clearly miscategorised (n=3983). The main interest is how each product category is split into more granular groups, which is considered for each category.

1.1.1.27.1 **Toys**

A total of 2,853 alerts in the 'Toys' category were identified. These alerts were identified across 10 product groups. The distribution of alerts within these groups is in Figure 7:

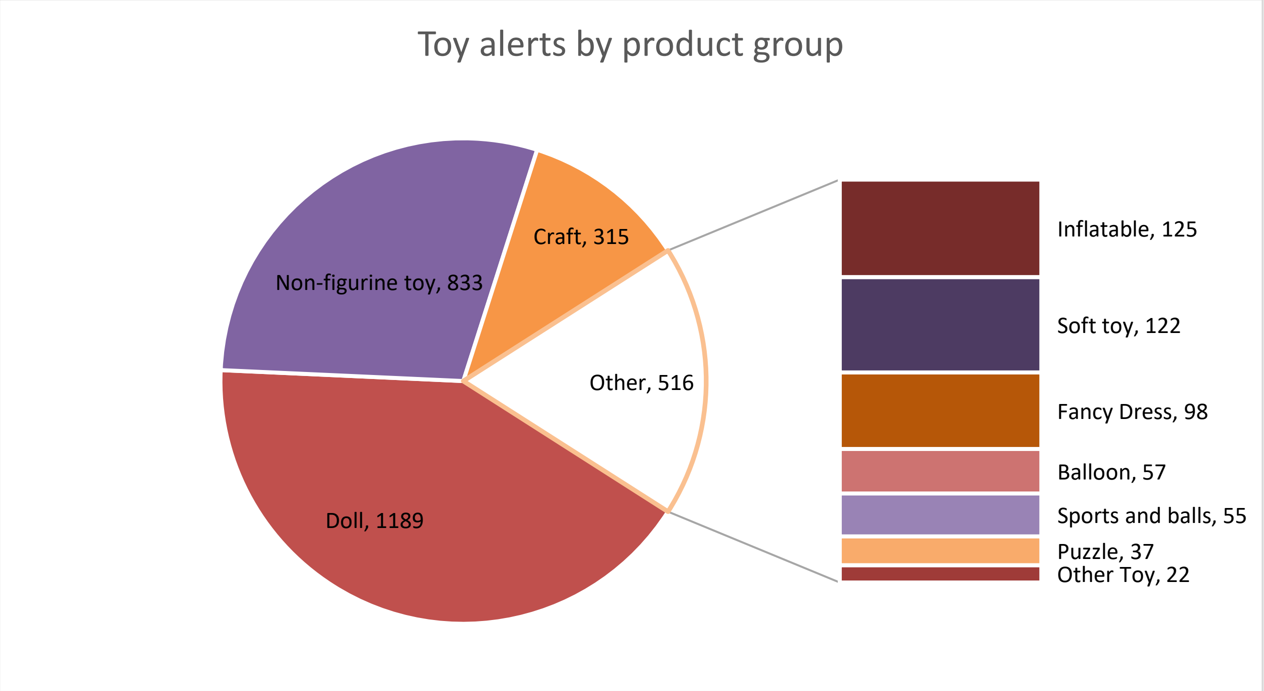

Figure 7: Number of toy alerts, by detailed product group

The 'Doll' and 'Non-figurine toy' category are by some distance the most regularly occurring category, accounting for 71% of all alerts. These are broad groups, and by and large refer to any humanoid figurines including pirates, superheroes, Barbie-style dolls for dress up, etc. or non-human toys and figurines, such as animals, trucks, children's kitchen play sets etc. Insufficient information was made to distinguish most products between material types Whilst a small number were explicitly described as being wooden, for the most part toys in these groups were labelled as plastic or had no material description and we can reasonably assume being plastic. This will be a mixture of hard (e.g. toy truck) or soft (e.g. Barbie-style doll) plastics. Toys in this category are generally designed to be held for long periods of time by children, which may impact dermal exposure to any contaminants. Children of a younger age may mouth products in these groups. Many dolls will also come with small parts or accessories such as fashion accessories, guns and swords etc. which could break off and be ingested.

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The next largest category for alerts was the 'Craft' category. This includes both stationery like pens and paints and tactile crafts such as clay, slime or plastic braids. The mixture of materials involved in this category makes conclusions on its relatively high alert frequency difficult. What is notable, however, is that products in this category are often designed to be touched or held by children (such as scoubidou or putty) or may leave behind liquids or other residues which could easily be ingested (pens, paints, slime etc.). This may lead to them having a higher risk profile than, say, sports items such as balls which will not necessarily be held indoors for prolonged periods.

The other product groups all had relatively small shares of alerts. The dominance of dolls and non-figurine toys in the sample is very notable. It is possible that this is simply a reflection of the number of toys on the market. However, a cursory look at available data from the US suggests this is not the case: in terms of toy industry dollar volume, the categories 'Action Figures & Accessories'; 'Dolls' and 'Vehicles' amounts to just 27% of the market.[9] There are many limitations with such a comparison, not least that cost per unit of different toy categories may be completely different, allowing many more dolls to be purchased for the same dollar value when compared to other toys and games. Nonetheless, it gives a quick and broad indication that something about the materials or production process of items in the 'Doll' and 'Non-figurine toy' groups is leading to higher frequency of toxic chemical contamination which would be worthy of further investigation.

As a secondary analysis, it is instructive to consider the country of origin of the products where alerts were raised. As mentioned in section 2.3.3.1, China is by an order of magnitude the primary source of products in the Safety Gate database, and one of our research questions (see section 1.1) relates to the differences between EU and non-EU products. The alerts by toy group and share of those alerts with non-EU* origin is presented in Figure 8. Note that for the purposes of this analysis, the EU* demarcation includes any country in the EU-27 plus the UK and Switzerland, and 'unknown' origin are considered non-EU*.[10]

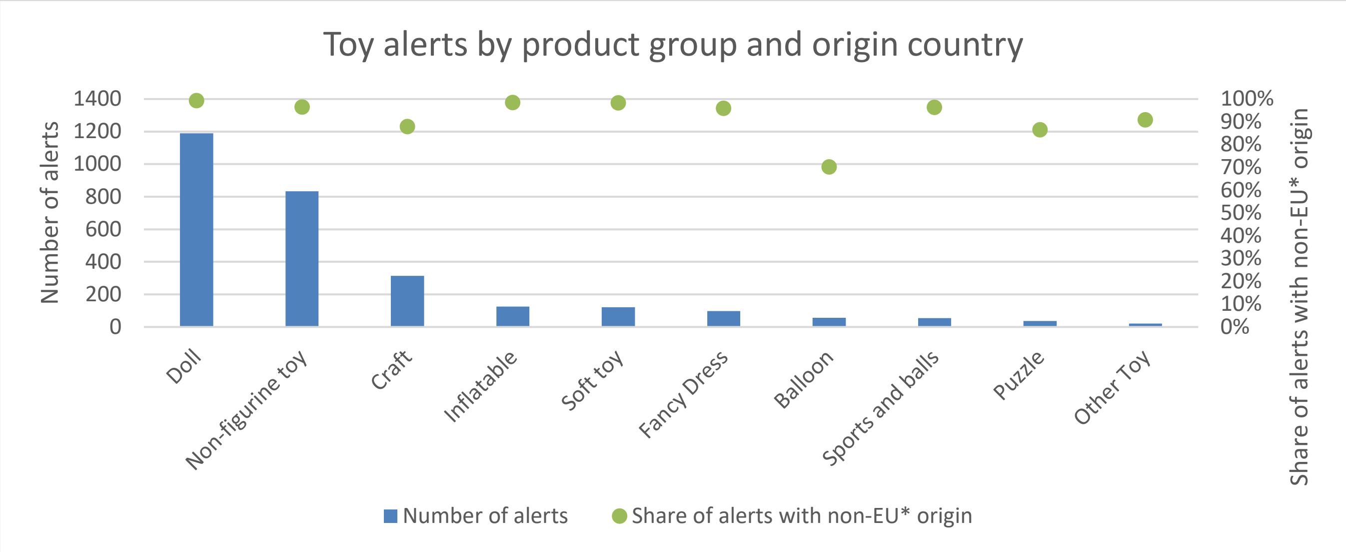

Figure 8: Toy alerts by detailed group and origin region

[9] https://www.toyassociation.org/ta/research/data/u-s-sales-data/toys/research-and-data/data/us-sales-data.aspx

[10] *Norway would similarly be included but no products in the dataset had Norway as a country of origin.*

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As China alone accounts for approximately 70% of the globe's toy manufacturing, it should be no surprise to see non-EU* countries accounting for such a large share of product alerts (S.-J. Chen et al., 2009). However, the share of alerts having a non-EU* origin being over 90% in nearly all product groups is striking, particularly the very high results for 'doll' and 'non-figurine toy' at 99% and 97% non-EU* respectively. China accounted for 97% and 85% of all alerts in these two groups, respectively. This would suggest particular problems related to the safety of primarily plastic toys from China which is disproportionate, even considering China's share of global toy manufacturing. This finding is important in the context of the fourth research question (see 1.1).

1.1.1.27.2 Clothing, textiles and fashion items

Clothing and textile items were the second most frequently identified product group: a total of 975 alerts in the 'clothing, textiles and fashion items' category were identified. These alerts were identified across 13 product groups. The distribution of alerts within these groups are presented Figure 9.

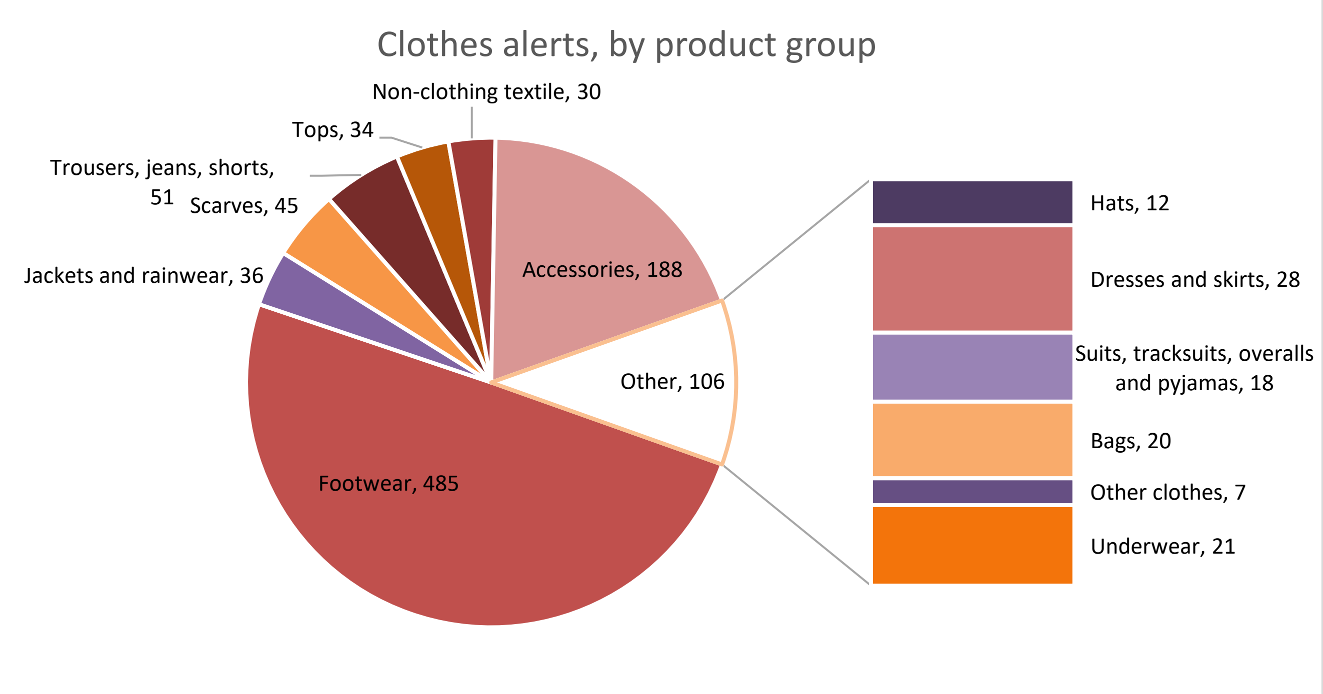

Figure 9: Number of clothes alerts, by detailed product group

Two groups are immediately notable for their high frequency of alerts: 'Footwear' and 'Accessories'. Together, these account for 69% of the alerts in this product category. The difference is so stark it can be said with confidence that this does not reflect the distribution of items on sale within the broader category, and there is therefore most likely something about the materials or manufacturing which leads to higher frequency of toxic materials.

One possible explanation relates to leather as it is a common material used in footwear of nearly all types, as well as being common in accessories such as watches, or leather gloves. To test this hypothesis, the original product name was searched for any reference to the word 'leather'. This was compared to the total alerts in that category. These results are displayed in Figure 10.

Figure 10: Share of clothing alerts known leather, by detailed group

It should be borne in mind that this only documents those products which explicitly mentioned leather in the product name. It could be the case that leather is so ubiquitous in footwear it may not seem necessary to specify, with product names instead focusing on type of shoe (e.g. 'sandals', 'trainer') or target market (e.g. women's shoe, men's shoe). It is therefore highly likely that a much higher percentage of footwear alerts contained leather than identified in Figure 10.

The preponderance of leather products appears to be driven almost entirely by chromium, which is a known issue in leather products due to the tanning process. Of those leather clothing product alerts with information on the chemical risk (36% of the leather clothing alerts), 84% of them directly referenced chromium in the description of chemical risk. This therefore relates to a known issue, and one which is possibly targeted by regulators for being known, which could lead to more alerts of this nature being raised.

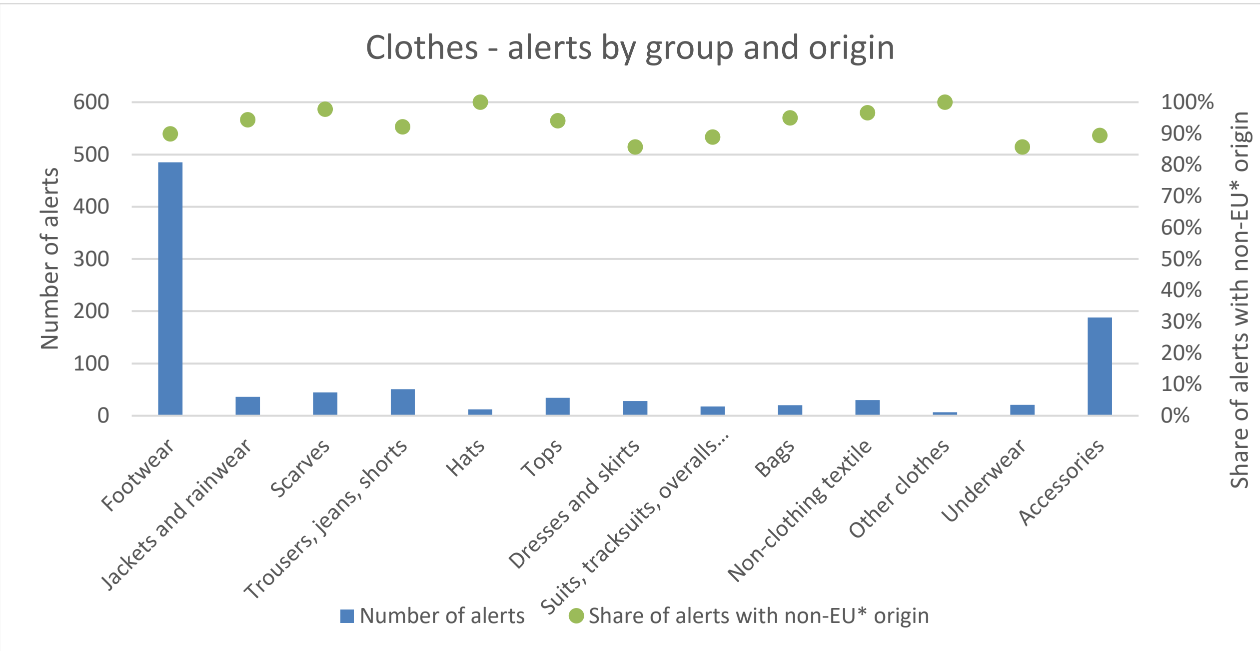

Figure 11: Clothes alerts by detailed group and origin region

As demonstrated in section 2.3.3.1, only 54% of clothes and textiles had China as the origin country. This reflects the greater role played by other Asian nations such as India and Bangladesh in the manufacturing of clothes and textiles. Despite a lower Chinese share of goods, as is shown in Figure 11, clothing and textile products with safety alerts overwhelmingly originated outside of the EU*, with nearly all product groups having at least 90% of product alerts originating outside the EU.

1.1.1.27.3 Childcare articles and children's equipment

A total of 104 alerts in the 'Childcare articles and children's equipment' category were identified. These alerts were identified across five product groups. The distribution of alerts within these groups and their origin region is displayed in Table 31.

Table 31: Childcare alerts and origin region, by detailed product group

Product groups	Number of alerts	Share of alerts in category	Share of alerts with non-EU* origin
Furniture	49	47%	57%
Bib	29	28%	59%
Soothers and bottles	15	14%	60%
Textiles and clothes	9	9%	89%
Other childcare	2	2%	100%

'Furniture', which encompasses baby seats, strollers, changing mats etc. is the group with the most frequent alerts raised, followed by baby bibs, which were frequent enough to warrant distinguishing from other textiles and clothes. Note that, due to inconsistency in labelling, some baby clothes may also be present in the 'Clothing, textiles and fashion items' category (section 2.3.3.2.2).

Like the 'Toys' category, one possible explanation for the distribution of alerts is the types of plastics used in products. Baby seats and changing mats may be made of hard plastic. Bibs can be made of textile or soft plastics which may allow for easy cleaning. The product names did not give information on the material composition in most cases so this is speculation.

Interestingly, when compared with the 'Toys' or 'Clothing, textiles and fashion items' categories, a far lower share of the most alerted product groups come from outside of the EU*. Whilst it is still a majority non-EU*, a non-trivial share amounting to nearly half of alerted baby furniture and bibs comes from within the EU*.

Due to the low body weight of infants and toddlers, toxic chemicals in materials with which they have contact is of particular concern.

1.1.1.27.4 Electrical appliances and equipment

A total of 30 alerts in the 'Electrical appliances and equipment' category, which includes both 'Electrical appliances and equipment' and 'Communications and media equipment' categories, were identified. These alerts were identified across three product groups. The distribution of alerts within these groups is in Table 32:

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Table 32: Electricals alerts, by detailed product group

Product groups	Number of alerts	Share of alerts in category
Headset & Speakers	7	23%
Power bank & charging	7	23%
Other electronic	16	53%

There are some notable trends when considering *within* the product groups, however, which is possible due to the very small numbers of products. Within 'Headsets & Speakers', five of the seven products (71%) explicitly describe being wireless (in the case of headphones) or portable (in the case of speakers) – this implies the presence of portable batteries and Bluetooth capabilities. The other two headsets do not specify whether wired or not and could feasibly be wireless or containing batteries. Six power-bank results relate to different alerts for the same product. Amongst 'other electronic', there is no clear trend other than a number being small electronic products. These products are detailed in the Technical Annex.

The small numbers of alerts make it difficult to draw meaningful conclusions. The relatively high number of small, battery-powered appliances may suggest that the chemical risk is mainly derived from batteries. As is identified section 2.3.3.3 approximately 83 alerts related specifically to batteries.

1.1.1.27.5 **Furniture**

All eight alerts for furniture items relate to sofas or chairs. All eight list China as the country of origin. This is too small a sample from which to derive any conclusions. It may be somewhat surprising that so few furniture alerts are raised given the use of flame retardants in furniture and furnishings. In fact, none of the eight furniture alerts list flame retardants as the reason for the risk: seven of the eight list the presence of the fungicide Dimethylformamide (DMF) causing skin irritation, with the last one also describing possibly allergic skin reactions but not describing the analyte. This may be due to the fact that flame retardants, whilst harmful in certain doses, are legal and even required in many countries. As a documentation system for chemical presence above expected and legal concentrations, Safety Gate would not be where ubiquitous but legal additives to furniture and upholstery would be documented.

1.1.1.27.6 **Motor vehicles**

A total of 13 alerts were identified in the 'Motor Vehicles' category. This was split across three product groups. The small number of alerts makes it difficult to draw meaningful conclusions about this product category. All alerted products listed a non-EU* origin country except one product in the 'Other motor' group: a spray paint for plastic materials in vehicles from Greece.

Table 33: Motor vehicle alerts, by detailed product group

Product groups	Number of alerts
Fabric or interior	5
Car part	6
Other motor	2

1.1.1.28 **Analytes**

Following the process of data cleaning and analyte extraction described above (section 0), the Safety Gate database was analysed. The 46% of alerts without 'Risk' information were filtered out from the dataset, leaving a final dataset of 2,190 alerts.

These alerts were then split based on the analyte focus groups, and is displayed in Figure 12:

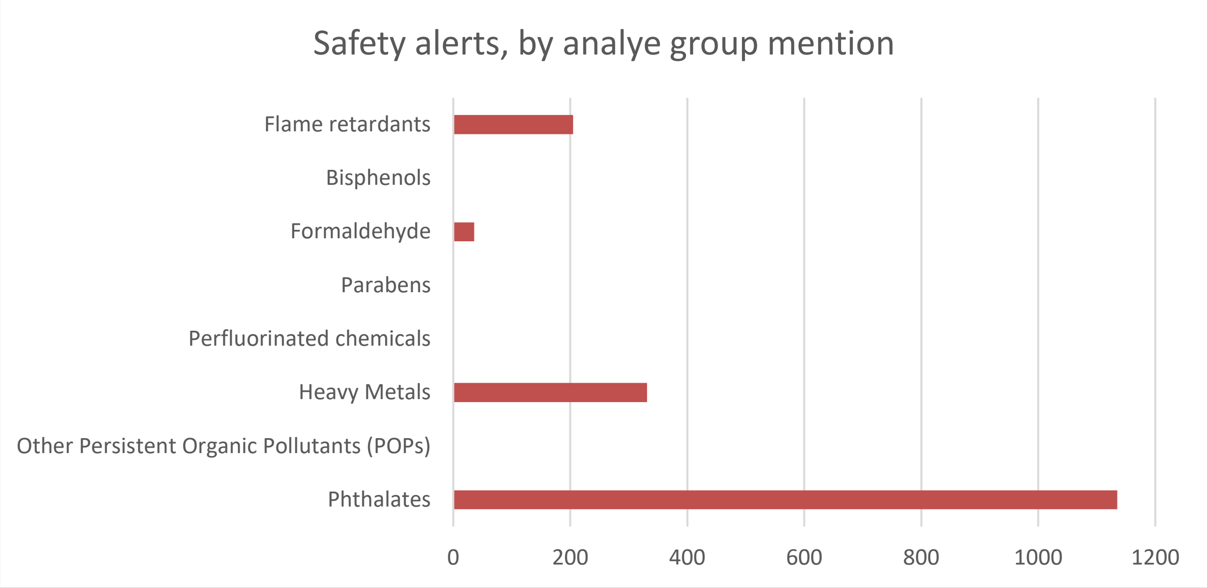

Figure 12: Safety Gate alerts, by analyte group mentioned

Note that the sum of alerts mentioning the focus group is larger than the 2,190 sample. This is due to some alerts mentioning analytes from multiple groups. Were a single alert to describe presence of both phthalates *and* heavy metals, for example, this would be considered twice in this table. It is notable that of the focus analyte groups, only phthalates, heavy metals, formaldehyde and flame retardants had any occurrences in the dataset. No mentions were identified of the other four analyte groups. This could reflect the scopes of the products considered: in the cosmetics category, some parabens were identified, for example (see the Technical Annex). Additionally, we cannot discount the possibility that the 46% of alerts with no risk description would include these analytes, or indeed the possibility of a bias in reporting whereby certain analyte groups are less likely to be detailed in the 'Risk' field. However, this is speculation and there is no clear reason why such a bias would occur. Similarly, it would be expected that even if such a bias did occur, we would see a small number of references to other POPs, perfluorinated chemicals, parabens or bisphenols. The complete absence suggests either limitations of the search terms used or that they are genuinely absent in these products.

In total, 1,486 alerts (68%) were identified as having *at least* one mention of a focus analyte group. The remaining 32% were considered in some depth to identify what, if not the focus analytes, were present with a number of separate search terms used (for a full list of search terms, see the Technical Annex). Combined, the focus- and non-focus analyte groups account for 2,055 alerts (94%). The remaining 6% will be a combination of other infrequent chemicals or unclear submissions which do not clearly label the chemical hazard. Of the non-focus analytes, some notable recurring chemicals include the anti-mould agent DMF (183 alerts) and Boron (138 alerts), as well as approximately 83 alerts which mention problems relating to the battery of an item. This preliminary analysis suggests that the majority of identified chemical hazards in our focus product groups come from just four of our focus analyte groups. These could therefore be the result of recycling-based contamination, or purposeful addition.

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Next, these four analyte groups are considered in more detail and divided between the product category in which the alerts were raised. The number of alerts with information about the focus analytes by product group are displayed in Table 34.

Table 34: Number of alerts relating to focus analytes, by product group

Product group	Alerts relating to focus analyte
Toys	1384
Clothing, textiles and fashion items	203
Childcare articles and children's equipment	90
Electrical appliances and equipment	24
Furniture	2
Motor vehicles	4

The distribution of these alerts between the four identified analyte groups is displayed in Figure 13. Note that this does not include alerts in these product groups which relate to non-focus analytes.

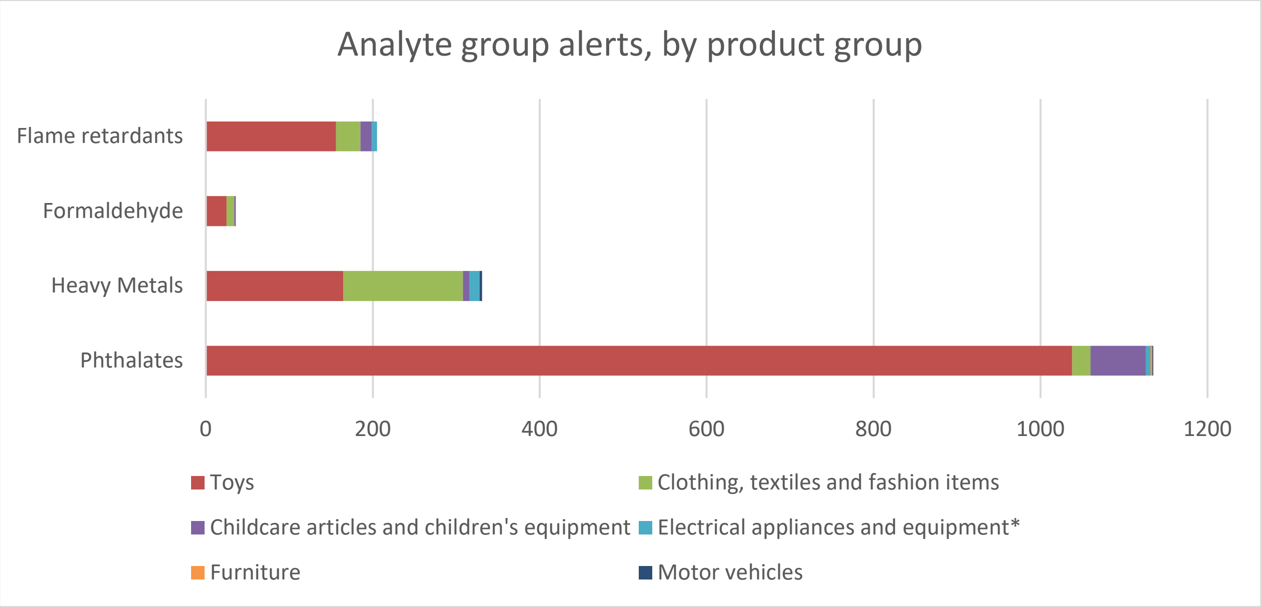

Figure 13: Share of relevant alerts by analyte and product group

The toys product category has the highest frequency of detection of all four analyte groups. This is particularly the case in the phthalates group, where 91% of all phthalate mentions relate to the toys category. Other than toys, clothing and textiles represents the next biggest source of the analytes and is particularly notable for the detection of heavy metals.

This distribution matches the overall distribution of alerts between these product categories (see section 2.3.3.1). What is notable is the relative frequency of phthalates in the toys and childcare equipment categories and the relative frequency of heavy metals in the clothes and textiles and electricals categories. The small numbers of furniture and motor vehicles datapoints makes it difficult to draw meaningful conclusions from the evidence.

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Based on the additional analysis of product categories into more granular product groups as outlined in section 2.3.3.2, it is possible to examine the relative frequency of analytes in more detail. This was done for the two categories with the most alerts raised, 'toys' and 'clothing, textiles and fashion items'.

1.1.1.28.1 **Toys**

Toys was the most common category with safety alerts in the analytes dataset. Toys were also regularly identified in the literature review (see 2.1.2.5) so were considered in more depth. The 'toys' category was split into the ten groups identified in section 2.3.3.2 and analysed for the frequency of each analyte group in alerts relating to those products. This is presented in Figure 14. Because this analysis contains only those products which have information in the 'Risk' field, the number of alerts in each product group is different from the samples discussed in section 2.3.3.2.1.

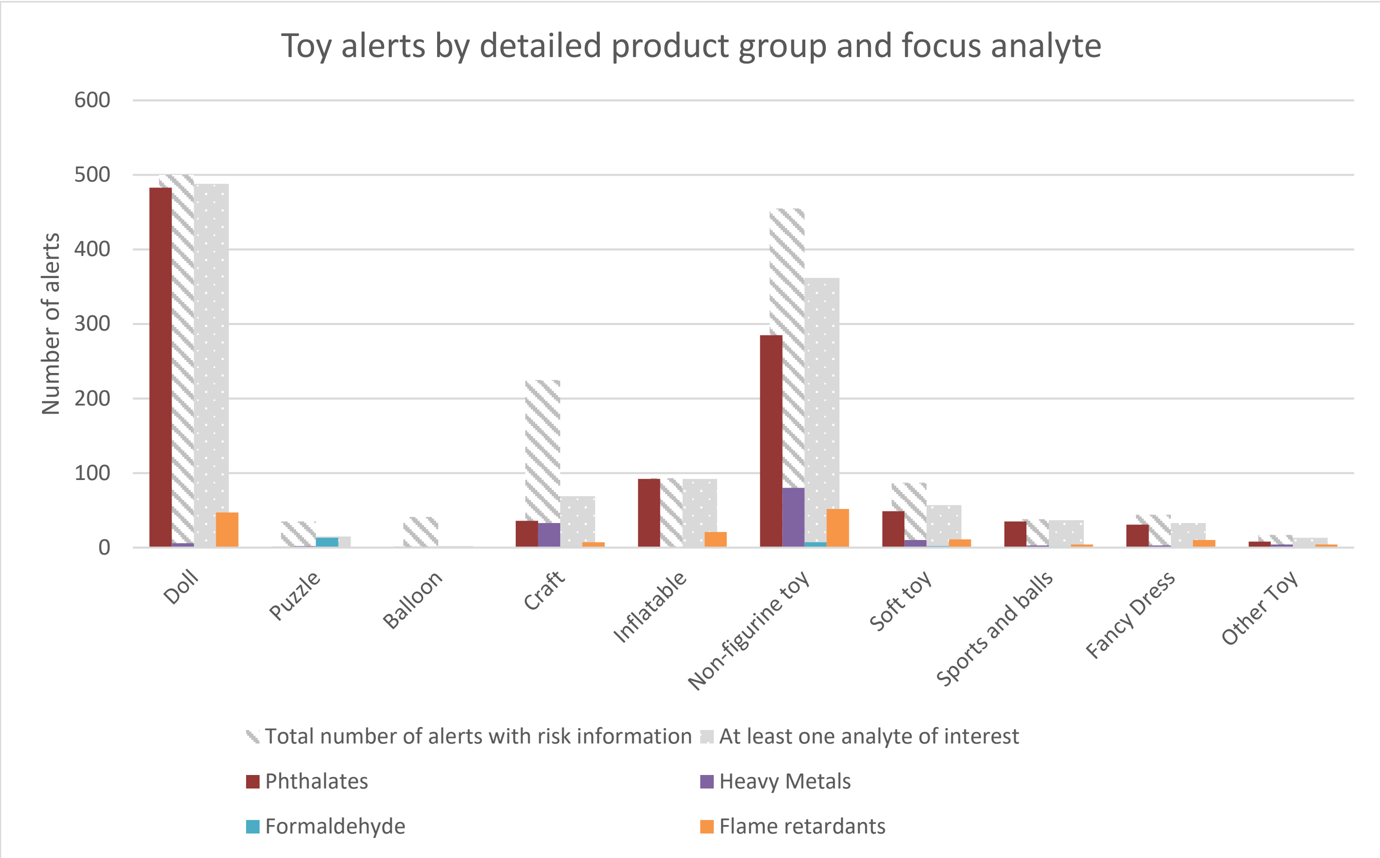

Figure 14: Toy alerts by detailed product group and focus analyte

One notable trend identified here is that our focus analyte groups are particularly common in certain product groups: 'dolls', 'inflatable', 'non-figurine toys' and 'sports and balls' had focus analytes in at least 80% of alerts. For 'dolls', 'inflatable' and 'sports and balls', almost all of these had phthalates present. The use of phthalates as a plasticiser to add flexibility and durability would offer a clear explanation for its presence, for example, inflatable goods such as swimming bands require the ability to change shape through inflation, sports gear such as balls requires durability for use and dolls will often have plasticisers to soften plastic. This would suggest that in most cases, alerts for toys are related to purposeful additives which have been used beyond legal limits. However, it is possible that excessive phthalate use, or use of banned substances, is a result of recycling, even if phthalates were originally purposefully added to many of these products.

Other notable results include the detection of flame retardants in a wide range of toys, ranging from 3% of alerts in the ‘craft’ category to as high as 24% in the ‘other’ category. Flame retardants are unlikely to be purposefully added to products for flame retardancy purposes, but some may be used as plasticisers. This also be an indication of recycled content contamination of a wide range of products.

The frequency with which formaldehyde was detected in puzzles is also notable. This may be due to the materials used: formaldehyde is often used in pressed-wood products. Puzzles are often made of wooden building blocks or paperboard in the case of jigsaw products. It is unclear if the formaldehyde would be purposefully added or if this indicates possible use of recycled construction materials in puzzles.

Heavy metals were found in nearly all toy categories. Other than the hard-to-define ‘other’ group, it was detected at a highest frequency in the ‘non-figurine toy’ group (18% of alerts). This is consistent with this group containing vehicular toys, which typically contain metal parts such as axles, as well as some small electronic goods such as remote-control cars.

In the cases of the ‘puzzle’, ‘balloon’ and ‘craft’ category, the majority of alerts were not analytes of focus for this study. This suggests that recycled materials is not a significant source of toxicity in these products.

1.1.1.28.2 **Clothing, textiles and fashion items**

Clothing, textiles and fashion items were the second-most identified product group in the analyte dataset. This product group was also regularly referenced in the literature review (see 2.1.2.3) so were analysed in more detail. The ‘clothing, textiles and fashion items’ group was split into 13 categories identified in section 2.3.3.2 and analysed for the frequency of each analyte group in alerts relating to those products. This is displayed in Figure 15. Note that the total number of footwear alerts with risk information exceeds what can be displayed on Figure 15, with a total value of 221.

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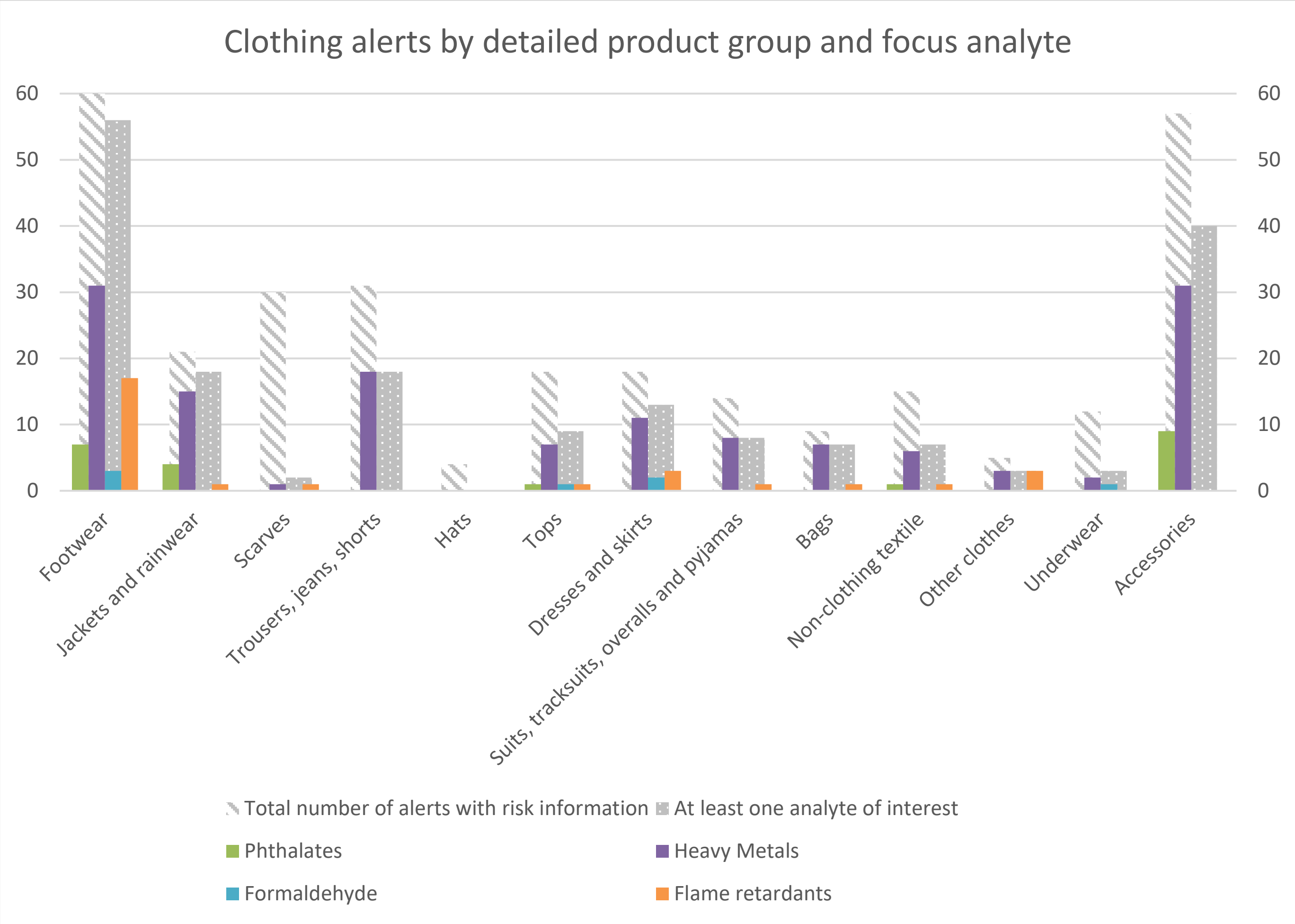

Figure 15: Clothing alerts by detailed product group and focus analyte

Five groups, ‘footwear’, ‘scarves’, ‘hats’, ‘non-clothing textiles’ and ‘underwear’ had more than half of all alerts relate to analytes not on our focus list. The presence of focus analyte groups was highest in ‘jackets and outwear’ (86%), ‘bags’ (78%), ‘dresses and skirts’ (72%) and ‘accessories’ (70%).

In most of the groups, no phthalates were mentioned in the product alerts. In two groups, ‘jackets and rainwear’ (19%) and ‘accessories’ (16%) more than 10% of alerts mentioned phthalates.

Heavy metals represent the most frequently mentioned analyte group in clothes, with all groups except ‘hats’ having heavy metals mentioned in some product alerts. This was highest in ‘bags’ (78%), ‘jackets and ‘rainwear’ (71%) and ‘dresses and skirts’ (61%). These represent products where zips may be expected to be found, which could serve as a possible explanation of metal contents.

Formaldehyde was infrequently mentioned in regards to clothes, but did appear in 11% of ‘dresses and skirts’ alerts. Because of the small sample size of ‘dresses and skirts’ (18), no real conclusions and comments can be made with any confidence.

Flame retardants were identified in a small number of alerts across most groups. The ‘other clothes’ group is notable in having by some distance the highest prevalence of flame retardants, in 60% of the alerts. However, the very small sample (5) of ‘other clothes’ means this relates to just three alerts. This result is not expected to represent a significant trend.

It is important to restate that, as previously mentioned (see section 0), this search process is imperfect and gives only a rough indication. In the cases for products with small samples, the results cannot be said with confidence to suggest particular trends.

Limitations and biases

There are a number of limitations to the Safety Gate dataset which caveat conclusions drawn from the results and their applicability to this scoping study.

Firstly, Safety Gate documents all chemical hazards in consumer products, with no information provided as to suggest which hazards or alerts may be related to use of recycled content. It therefore provides an overview of chemical hazards in consumer products more generally, but does not directly answer the question of whether there are chemical risks associated with use of recycled content. Its findings must be used in conjunction with the findings of the other parts of the scoping study.

Secondly, the level of detail in alert documentation is highly variable. In some cases, detailed information of chemical hazard and product type are offered, in others this information is missing: as many as 46% of chemical alerts do not describe the risk. This is a very substantial data gap, and it is possible that there may be biases in the data which is missing, leading to certain trends in chemical alerts not being identified.

A third, important limitation of the reporting structure is that these alerts do not necessarily reflect the distribution of chemical hazards, but may instead reflect the distribution of enforcement. This is particularly expected to have an influence on the high frequency of toy alerts: as articles for children, toys have heightened interest and if there are known issues, such as phthalates in imported toys, regulators may target these products for testing. Due to cost limitations, not everything can be tested, and relatively heightened interest in one product group may mean that other product groups are not tested as regularly. The role of increased enforcement in the toy sector was a point corroborated by stakeholders in the engagement section of this research (see 4.0).

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Surveys and Interviews

Stakeholder survey

Method

Surveys were undertaken to provide complementary information to the literature review and help understand how manufacturers, retailers and reprocessors understand and engage with issues pertaining to chemical hazards and use of recycled content.

Two surveys were carried out. One was aimed at manufacturers and own brand retailers, the second was aimed at reprocessors and recyclers. These shall be referred to as the 'manufacturer-retailer survey' and the 'reprocessor survey'. The surveys used convenience samples and were completed on a voluntary basis. The surveys were advertised through WRAP's business contacts and email listings as well as online, using WRAP's LinkedIn page. As a result of convenience sampling, the results cannot be considered to be representative of businesses in the UK, and there is a bias towards companies which are already engaging with WRAP on other sustainability issues. This was considered an acceptable limitation for the purposes of the scoping study, but does mean that results must be caveated for being a small and unrepresentative sample.

The two surveys were carried out online using Surveymonkey. The results are anonymised and no data was collected which would identify the respondent, other than the contact details of those volunteering for participation in the in-depth survey interviews (see section 3.2). The survey was live for two weeks in May 2021. The surveys each had eighteen core questions, with some sub questions. These varied between questions with a single answer, multiple choice questions and open-text responses. The pertinent findings are presented below. As has already been mentioned, **the small samples and method of sampling means that the findings are indicative only.**

Results

1.1.1.29 Manufacturer-retailer survey

1.1.1.29.1 Respondent Profile

There were 58 respondents to the manufacturer-retailer survey. Half of respondents identified as manufacturers, with a further 26% both manufacturing and retailing goods.

Table 35: Distribution of business types in manufacturer-retailer survey

Are you a manufacturer or an own brand retailer?	Number of responses	Share of total responses
Manufacturer	29	50%
Own brand retailer	14	24%
Both – Manufacturer and own brand retailer	15	26%

Respondents were asked to indicate the product groups they manufactured or sold. Some 57% of respondents indicated that they manufactured a single product category, the remaining 43% manufactured multiple product groups. The distribution of responses by product type is displayed in Figure 16. Note that respondents could indicate selling more than one product group, so the sum of responses exceeds the number of respondents (n=58).

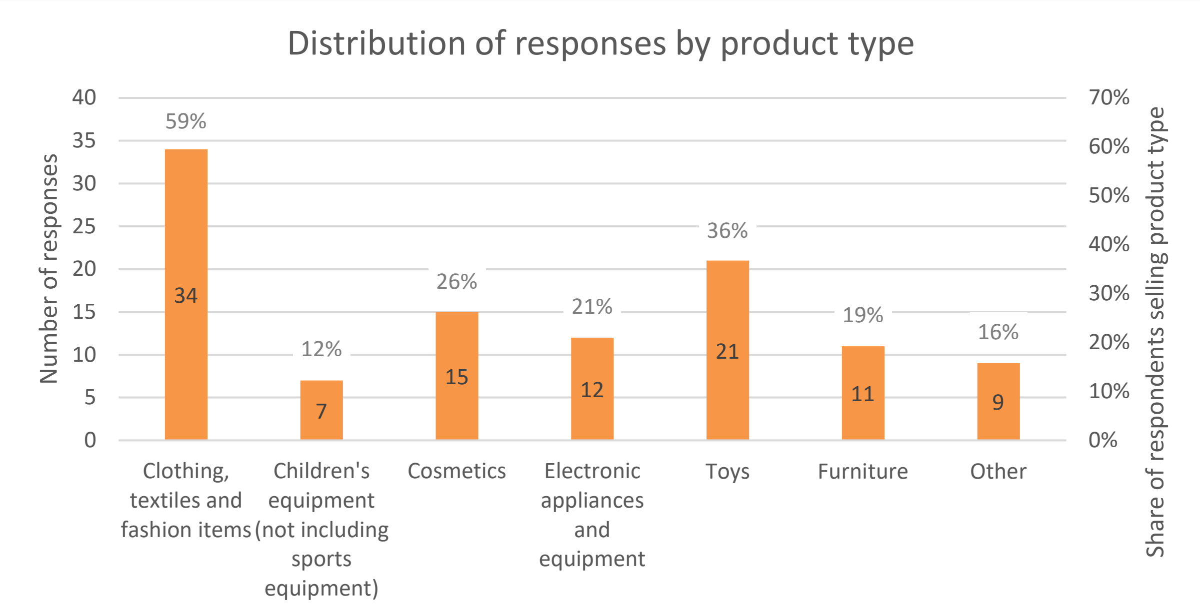

Figure 16: Distribution of product groups manufactured-sold in manufacturer-retailer survey

There were no respondents who manufactured or sold motor vehicles, which was the only priority product group (see section 1.3.1) which was not represented in the survey. Motor vehicles are outside of the regulatory remit of OPSS. The most common product group was clothing, textiles and fashion items, which 59% of respondents indicate that they manufacture and/or sell. The 'other' responses mainly centred around home textiles and over-the-counter medicines.

The majority (90%) of respondents sourced materials from outside the UK, primarily in Asian countries including India and China.

1.1.1.29.2 **Recycling practices**

Respondents were asked to indicate their use of recycled content. The majority (79%) of respondents indicated that they do use recycled content in their products.

Table 36: Use of recycled content in manufacturer-retailer survey

Do you use recycled content in your products?	Number of responses	Share of total responses
Yes	44	79%
No	12	21%

Of those which do not use RC, they were asked to indicate the primary reasons for this decision. The responses are displayed in Figure 17. What is notable is that the most cited reason for not using RC was regulatory and safety concerns. Two-thirds of those not using RC cited this as a main reason. The two other most cited reasons relate to availability and quality of recycled materials.

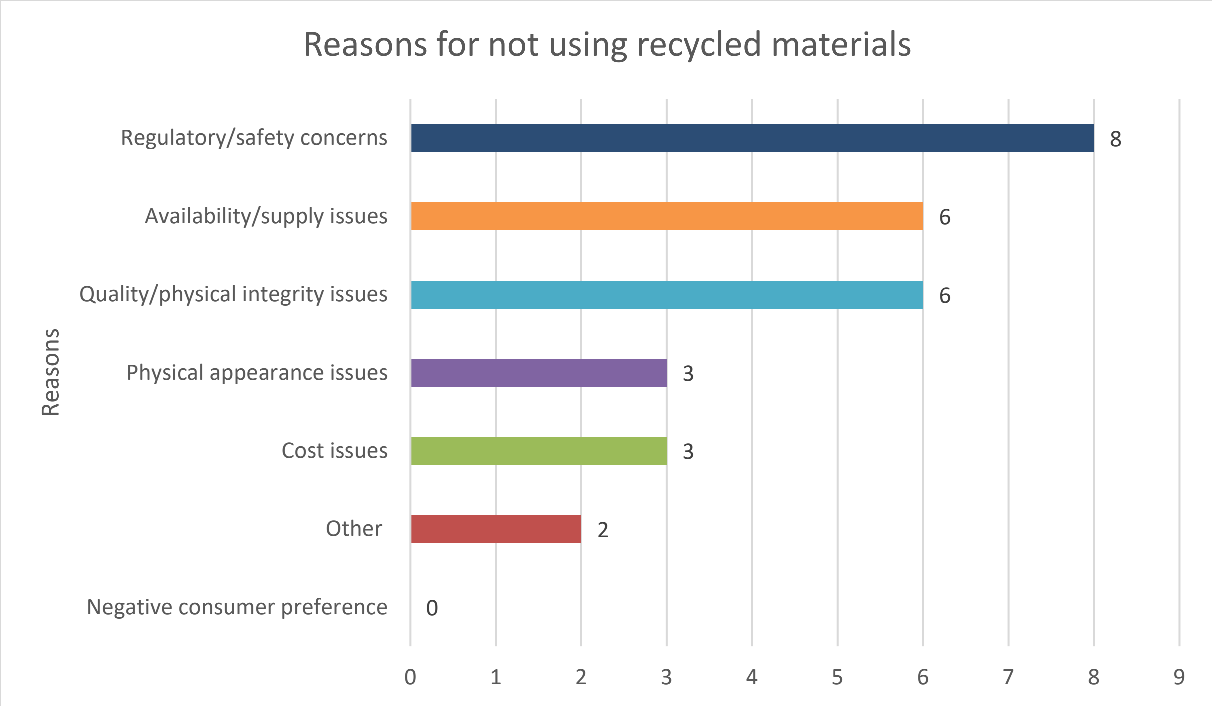

Figure 17: Reasons for not using recycled materials in manufacturer-retailer survey

Respondents indicating that they do use RC, were asked to identify the primary three factors they look for when sourcing RC. The results are displayed in Figure 18. Four primary concerns are indicated: price; quality; adherence to regulatory requirements; certification. The importance of price and quality is perhaps unsurprising, but the results also point towards traceability and transparency issues being particularly important.

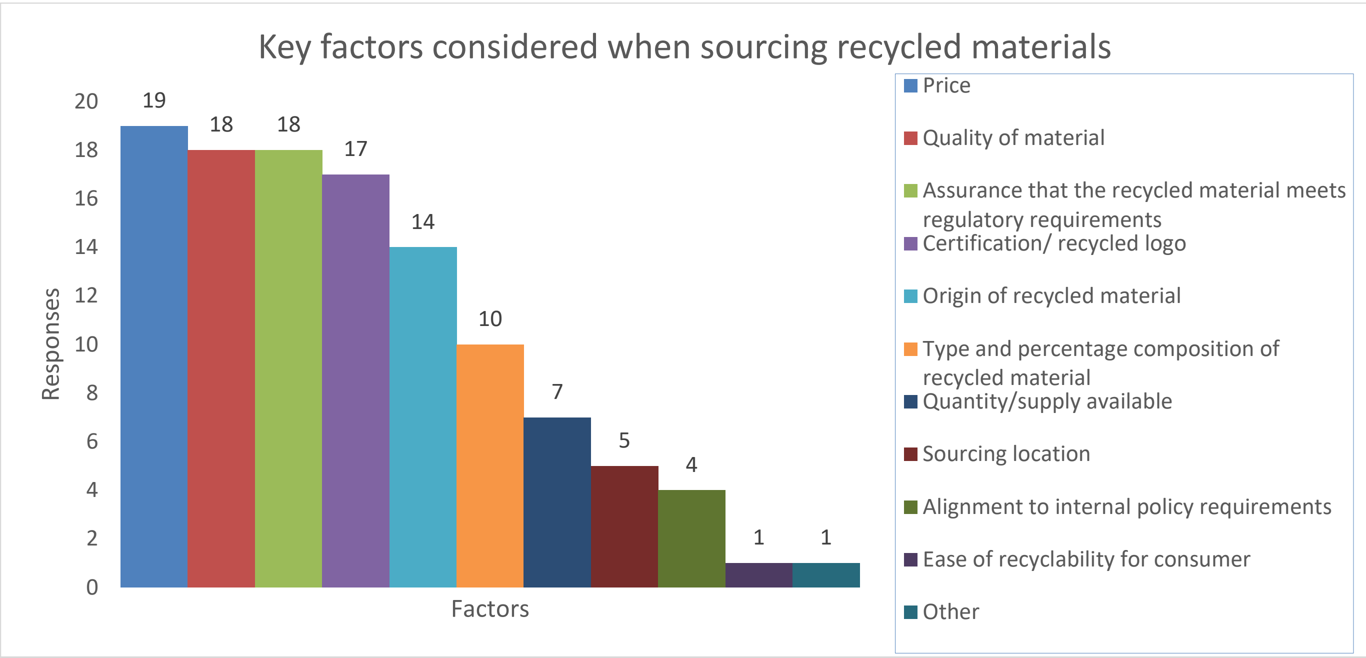

Figure 18: Key factors for sourcing recycled materials in manufacturer-retailer survey

When asked about the differences between imported and UK-sourced RC, 68% indicated that they do not perceive a difference. The 32% indicating a difference were asked to explain those differences, and three main themes were identified from their responses:

- Availability, particularly regarding recycled fabrics and yarn, where the UK lacks manufacturing capabilities.
- Price, where the UK is considered more expensive to source from for the same material.
- Quality, where UK-sourced RC may be insufficient for specific purposes, such as food-grade packaging.

Respondents were also asked about blending recycled materials. Of the respondents, the majority (76%) did say they blend materials. However, this question had a notably high non-response rate, with 43% of survey respondents skipping the question. It is possible that there is a bias amongst those who did not respond, if they perceived one of the responses as less socially desirable.

Table 37: Recycled material blending in manufacturer-retailer survey

Do you blend recycled materials with virgin materials?	Number of responses	Share of total responses
Yes	25	76%
No	7	21%
Prefer not to say	1	3%

When the results were split between product groups manufactured and/or sold, the results were broadly consistent with the distribution of products represented in the survey - 14-18%reported not using blended RC across all product types. This suggests that the use – or non-use – of blended RC is not driven by the specificities of manufacturing certain products.

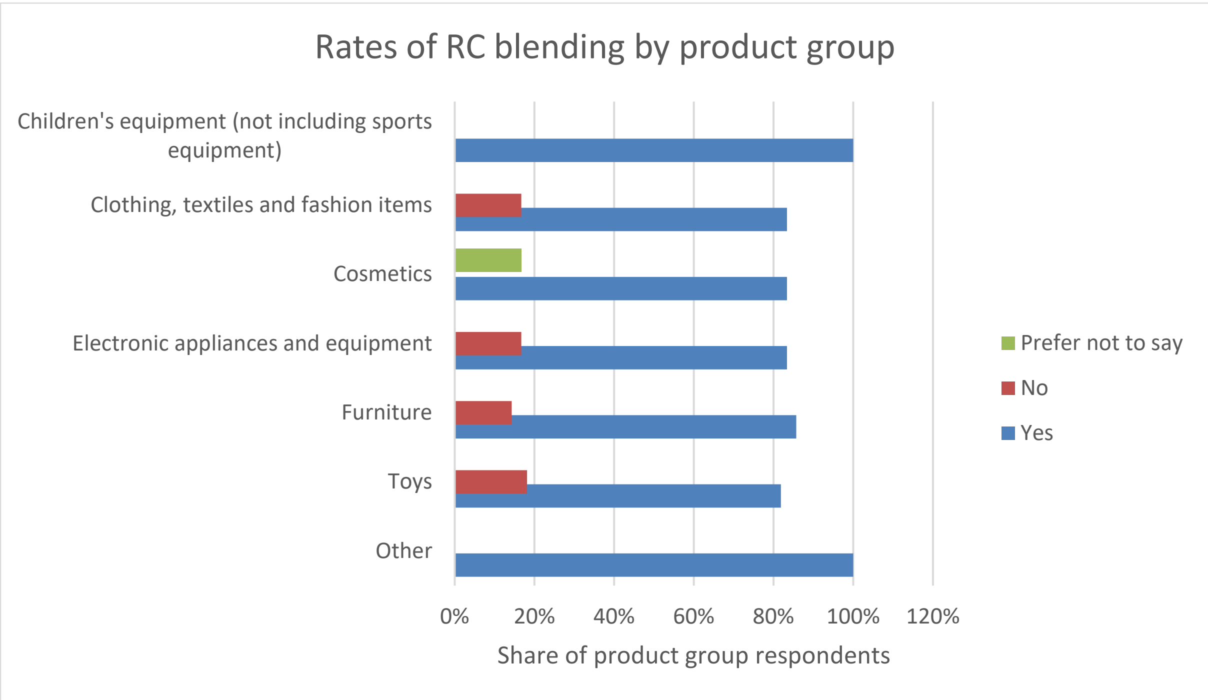

Figure 19: RC blending by product group in manufacturer-retailer survey

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When asked directly as to why manufacturer and/or retailers use blended RC, three key reasons emerged: cost; durability; aesthetics. The full results are displayed in Figure 20. It is notable that reasons relating to chemical safety, such as reducing concentration of specific chemicals or meeting regulatory requirements, were rarely cited as reasons for using blended materials. This suggests that the extent to which blended materials could reduce the toxic chemical risk of RC use is an incidental by-process of blending which is done to meet other financial and quality objectives.

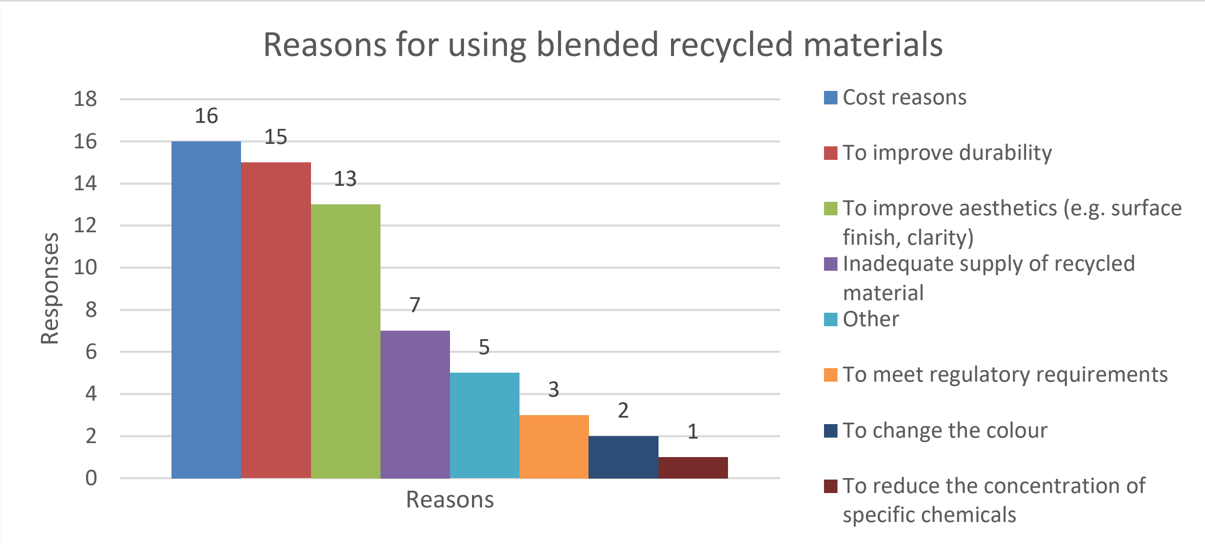

Figure 20: Reasons for using blended RC in manufacturer-retailer survey

1.1.1.29.3 **Regulations and chemical testing**

Respondents were asked a series of questions to understand their awareness of chemical safety concerns and what they do to address those concerns.

The majority of respondents (67%) had self-reported awareness of regulatory requirements for recycled feedstock. Those responding ‘other’ elaborated by clarifying that this information was in the process of being gathered, or that other relevant colleagues in the organisation, including sourcing offices, would have the information. It should be noted that this question had a high non-response rate: 58% responded to this question. If discounting the respondents who do not use RC, 28% of respondents who *do* use RC did not respond to this question. It is possible that this non-response rate reflects a social desirability bias in which awareness of regulatory requirements is perceived as the desirable or ‘correct’ answer, discouraging those unaware of them from responding as such. This adds a caveat that the survey could possibly overstate the degree of regulatory awareness.

Table 38: Awareness of regulatory requirements in manufacturer-retailer survey

Are you aware of the regulatory requirements that are in place for the recycled feedstock material you use?	Number of responses	Share of total responses
Yes	22	67%
No	9	27%
Other	2	6%

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When split by product group (Figure 21), awareness is broadly even across categories: approximately 50-70% indicate being aware, with 15-30% being unaware. The notable exceptions are Children's equipment and Furniture. There was a single respondent to this question who manufactured-sold children's equipment, so these results cannot be taken to meaningfully suggest any particular trend. More interesting is furniture, where six respondents were evenly split between awareness and non-awareness: whilst the number of respondents is small, it is comparable to those in cosmetics (seven), electronics (six) and toys (six). This suggests that regulatory awareness is slightly lower in the furniture industry, although the small samples and high non-response rate means there is low confidence in this finding.

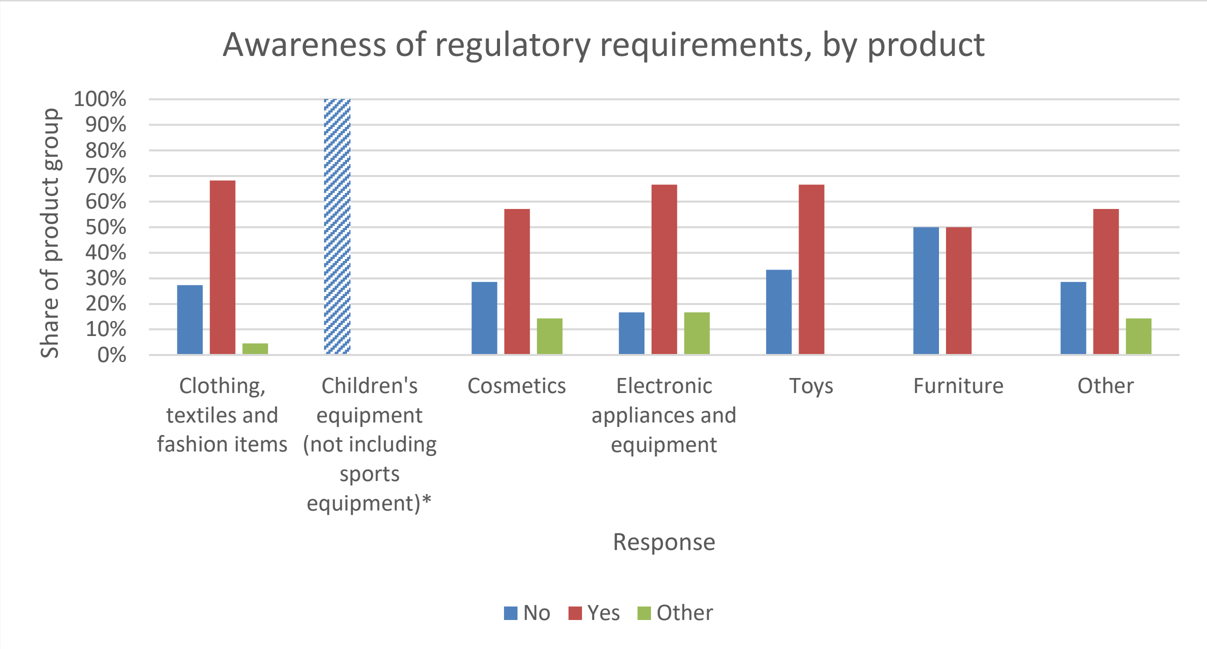

Figure 21: Awareness of regulatory requirements by product group in manufacturer-retailer survey. *Note children's equipment had a single respondent.

When asked to describe the physical and chemical safety constraints respondents faced when using RC, the results were divided: about one third of respondents suggested that RC either does not present chemical and physical constraints in their work, or at least that those constraints are not *additional* to the ones presented by virgin feedstock. For other respondents who did identify constraints, the recurring issues were those of inconsistent material and performance issues. Respondents regularly raised the need to adhere to regulatory requirements such as REACH in their concerns about RC. Although this suggests that for a non-negligible number of respondents, the use of RC does not throw up extra physical/chemical safety barriers, for many respondents regulatory requirements were a concern.

Respondents were asked about how they identify when materials have met regulatory requirements. They were allowed to select multiple responses, however two responses were the most commonly reported primary routes of identification: documentation and independent reports, and testing carried out by suppliers (these are not mutually exclusive: the supplier may have contracted independent reports). As with some other questions about RC, 43% of respondents (of whom 48% indicated that they do not use RC) did not provide an answer to this question. This is particularly notable because of the 57% who did respond, 27% indicated that they do not actively look for information on regulatory adherence.

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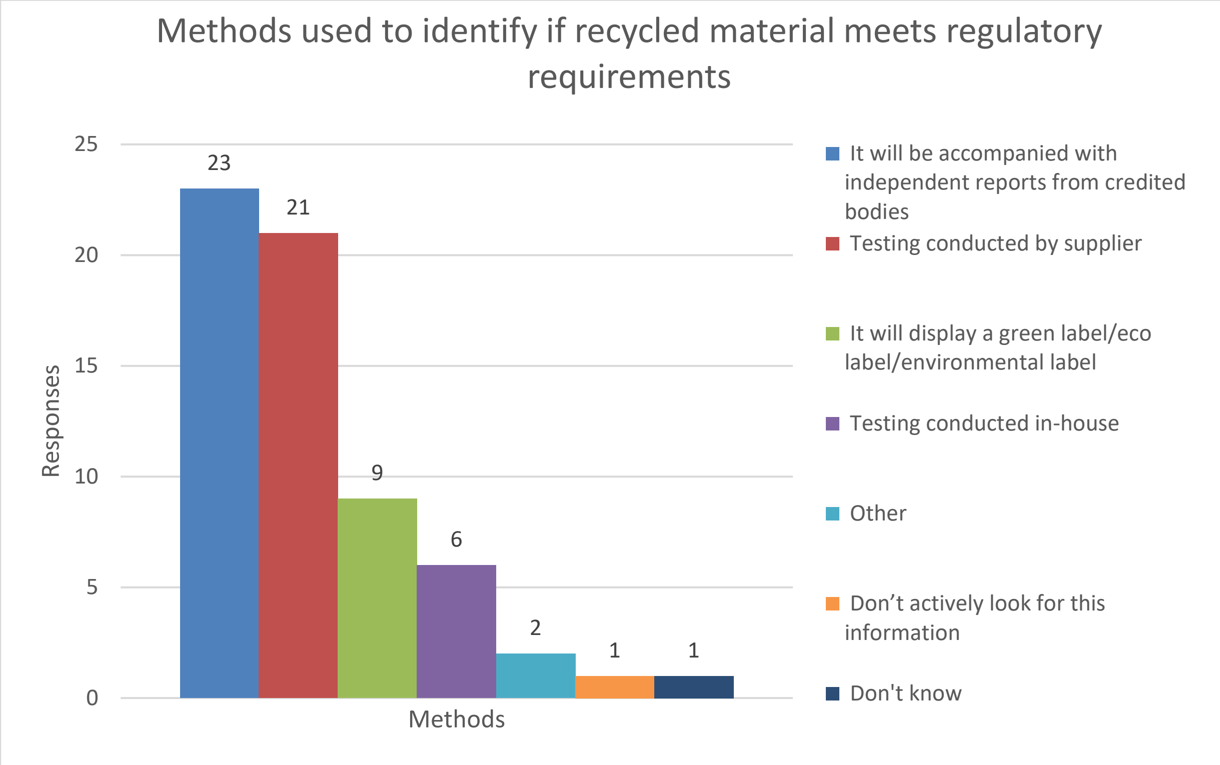

Figure 22: Methods of identifying RC regulatory adherence in manufacturer-retailer survey

Respondents were asked questions relating to stakeholder responsibility for regulatory adherence. They were asked both ‘at present who *does* hold the responsibility?’, and ‘who *should* hold the responsibility?’ The results for who *does* presently hold responsibility is presented in Figure 23. Most respondents indicated that the supplier, manufacturer and, to a lesser extent the retailer hold the most responsibility. Very few respondents thought regulators or reprocessors held responsibility. What is particularly notable is that manufacturers who do not also sell their product were the primary group to suggest that the manufacturer currently bears responsibility, suggesting that this group views itself as playing a central role in chemical safety. Those who both manufacture *and* sell goods were more likely to suggest the supplier of the material, rather than the manufacturer of the product, is where responsibility lies.

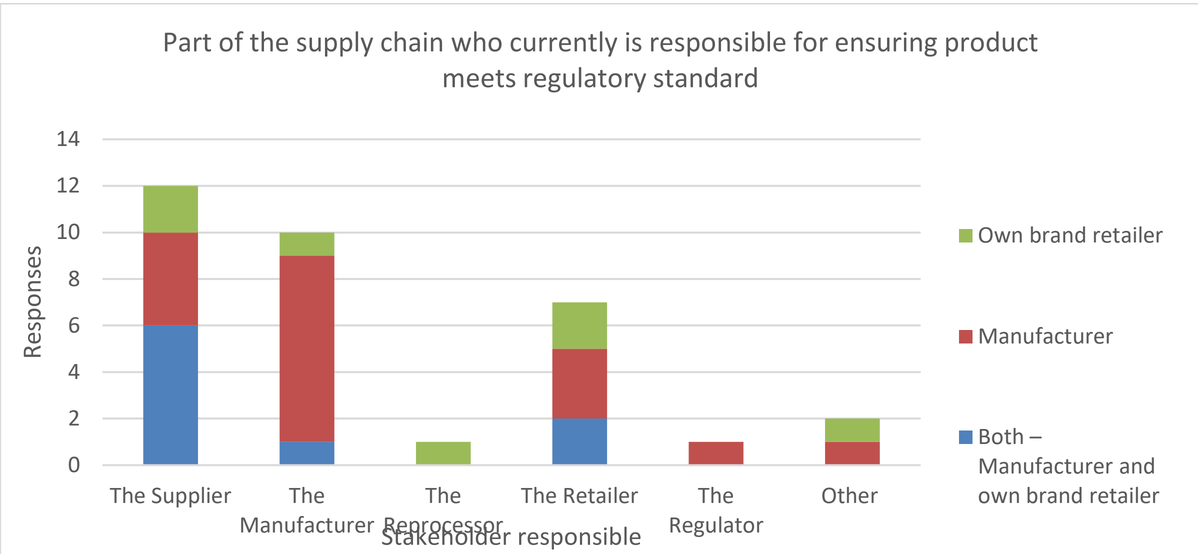

Figure 23: Part of the supply chain who is responsible for ensuring product meets regulatory standard

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The responses to who *should* bear the most responsibility are presented in Figure 24. The responsibility of the manufacturer is heightened in these responses, with twice as many respondents saying the manufacturer bears responsibility than the next most selected response, the supplier. Therefore the responsibility which is currently identified as being on suppliers is largely suggested as something which *should* be on manufacturers. Retailers who did not also manufacture goods indicated that responsibility should lie elsewhere in the supply chain; none suggested responsibility should fall on retailers. Three retailers reported that the regulator should have more responsibility than it currently does. As in Figure 23, the majority of those indicating that responsibility should lie with manufacturers are manufacturers themselves.

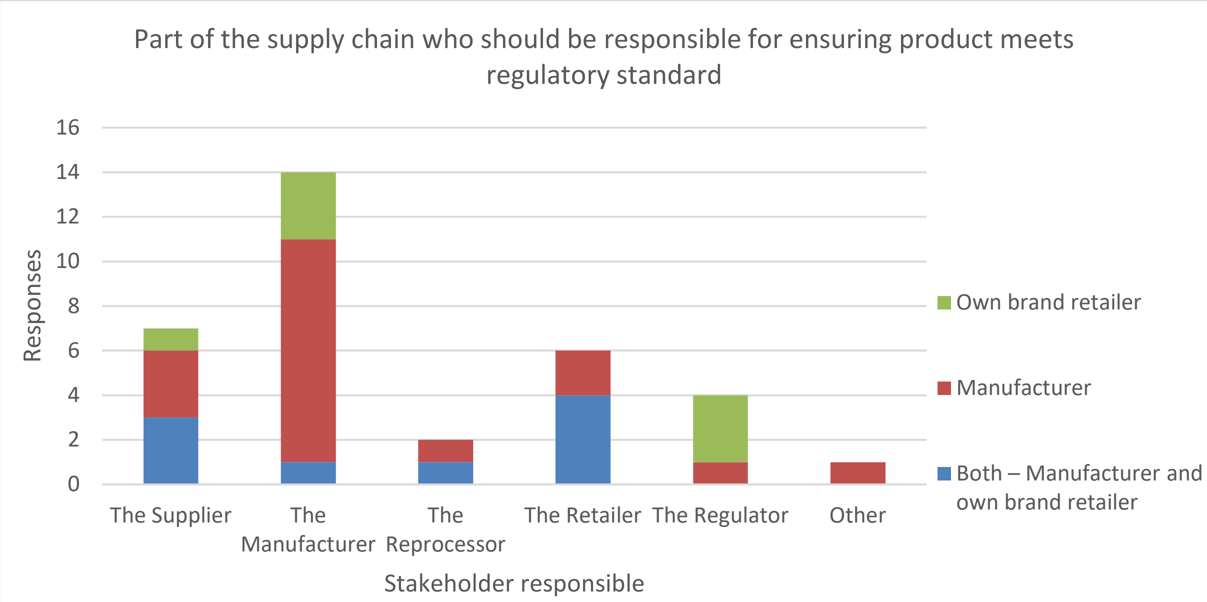

Figure 24: Part of the supply chain who should be responsible for ensuring product meets regulatory standard

Respondents were asked to indicate their level of concern about the chemical safety of the materials they use. The results are presented in Figure 25. These are divided by business type in Figure 26 and by product group in Figure 27. There is an interesting divide, with those 'extremely' and 'moderately' concerned nearly perfectly mirrored by those 'slightly' or 'not at all' concerned. These responses are not evenly distributed between business group: a larger share of manufacturers are not at all concerned than any other group. By product group, the distribution again varies by product group: the 'not at all concerned' group is overwhelmingly made up of those manufacturing-selling clothing, textiles and fashion items. By contrast, those who manufacture-sell electronics and toys had a higher share of respondents indicating extreme concern.

Respondents were asked to give reasons for their level of concern. It should be noted that amongst those with slight or no concern, it was not because they viewed chemical safety as unimportant. Instead, the recurring themes from these respondents pointed towards confidence in the testing and safety regime they currently employ, including an expectation that upstream in the supply chain these issues are addressed when retailers purchase from trusted and certified suppliers. Some indicated that their not using RC, or using controlled RC from pre-consumer sources was what reduced their level of concern. Amongst those indicating moderate or extreme concern, the majority cited regulation and legislative limits, with a smaller

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number indicating that the reason for their concern was not regulatory limits but their desire to be a responsible seller of safe products.

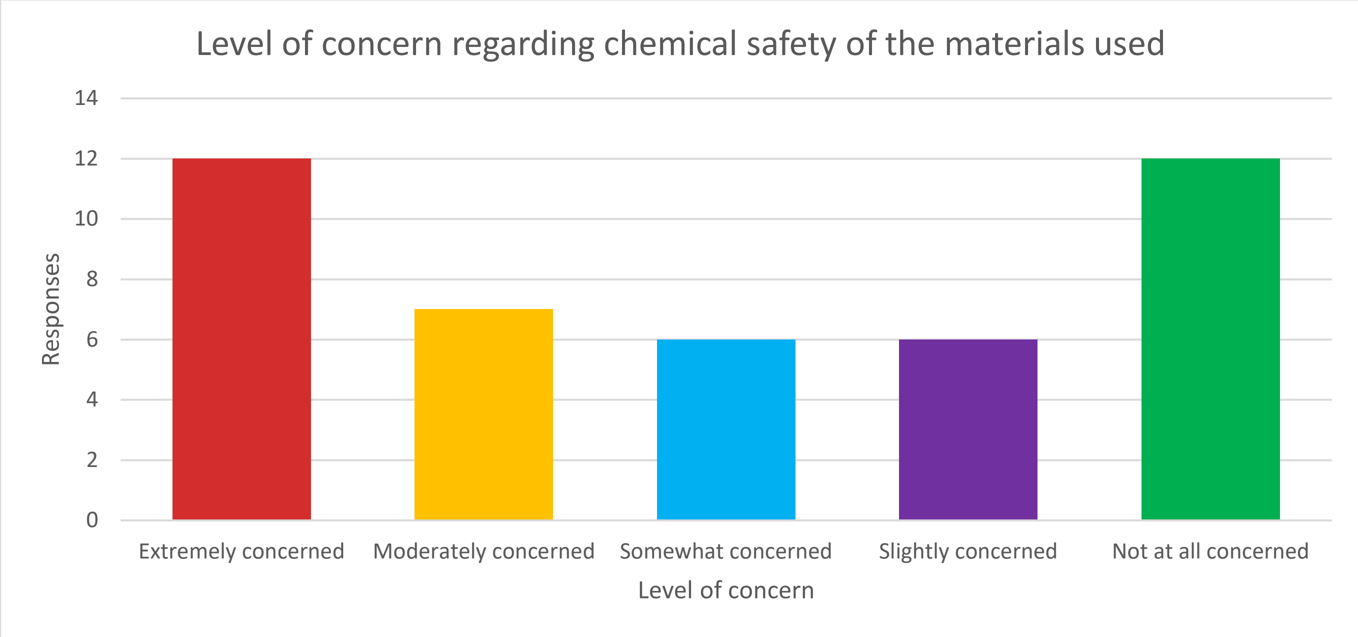

Figure 25: Level of chemical safety concern

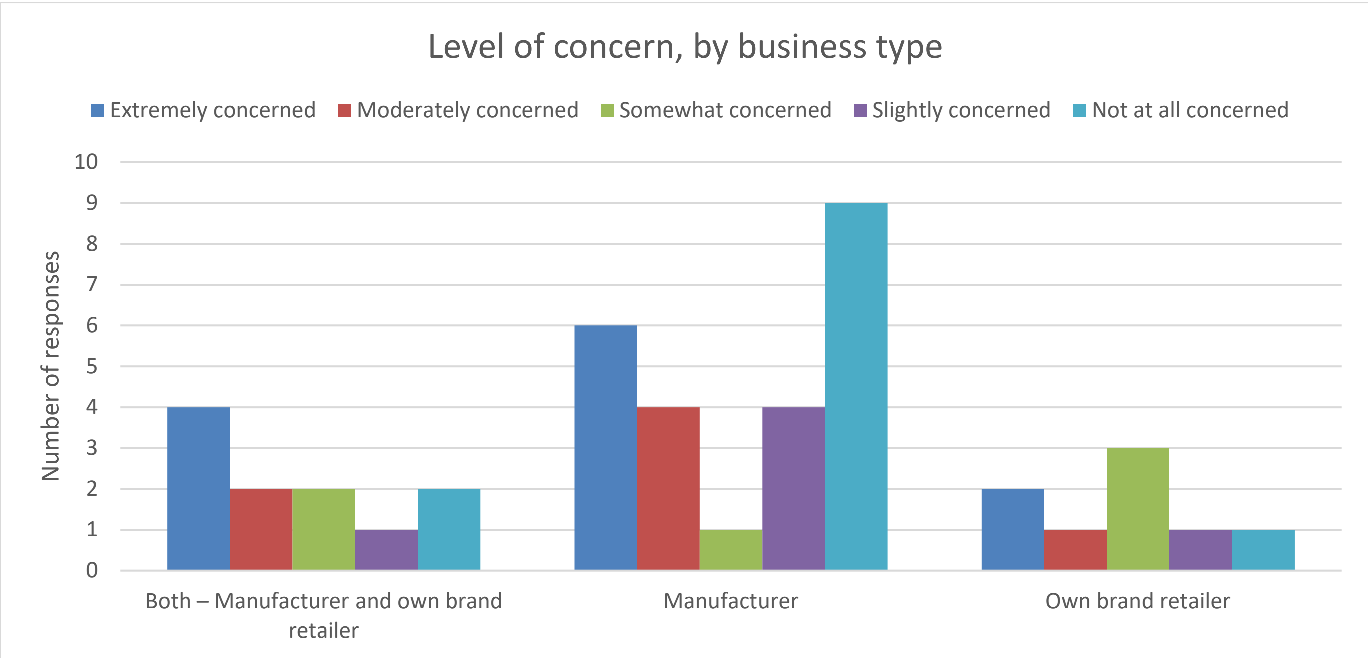

Figure 26: Level of chemical safety concern, by business type

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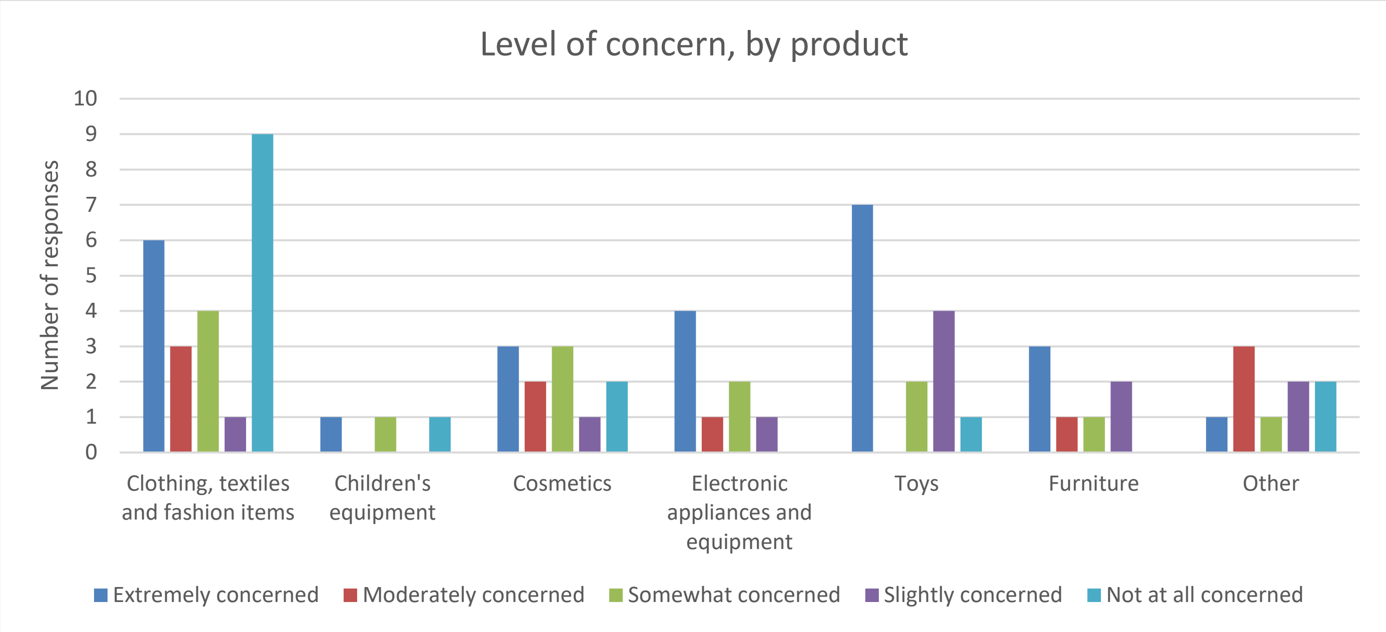

Figure 27: Level of chemical safety concern, by product group

Respondents were asked about the testing of materials. A majority of respondents (77%) indicated that they test materials for toxic chemicals and hazardous substances. High self-reported testing was identified across all product groups. The notable exception was clothing, textiles and fashion items, where 35% indicate that they do not test materials, higher than the average non-testing rate (23%). Where possible, some respondents indicated this was due to using certified materials which adhere to an existing standard, such as OEKO-TEX 100. Of those who do carry out tests, they were asked to indicate what analytes they test for. The results are presented in Figure 28. This suggests that most of the priority chemical groups in this study were tested for, with particular attention paid to phthalates (76% of those reporting conducting tests test for phthalates), heavy metals (70%) and formaldehydes (61%). With just 15% of those reporting doing tests testing for parabens, this was the least tested for substance. Of those testing for ‘other’ chemical groups, respondents mainly indicated lists relating to specific standards or regulations: REACH chemicals, OEKO-TEX and EN 71-3 standards coming up.

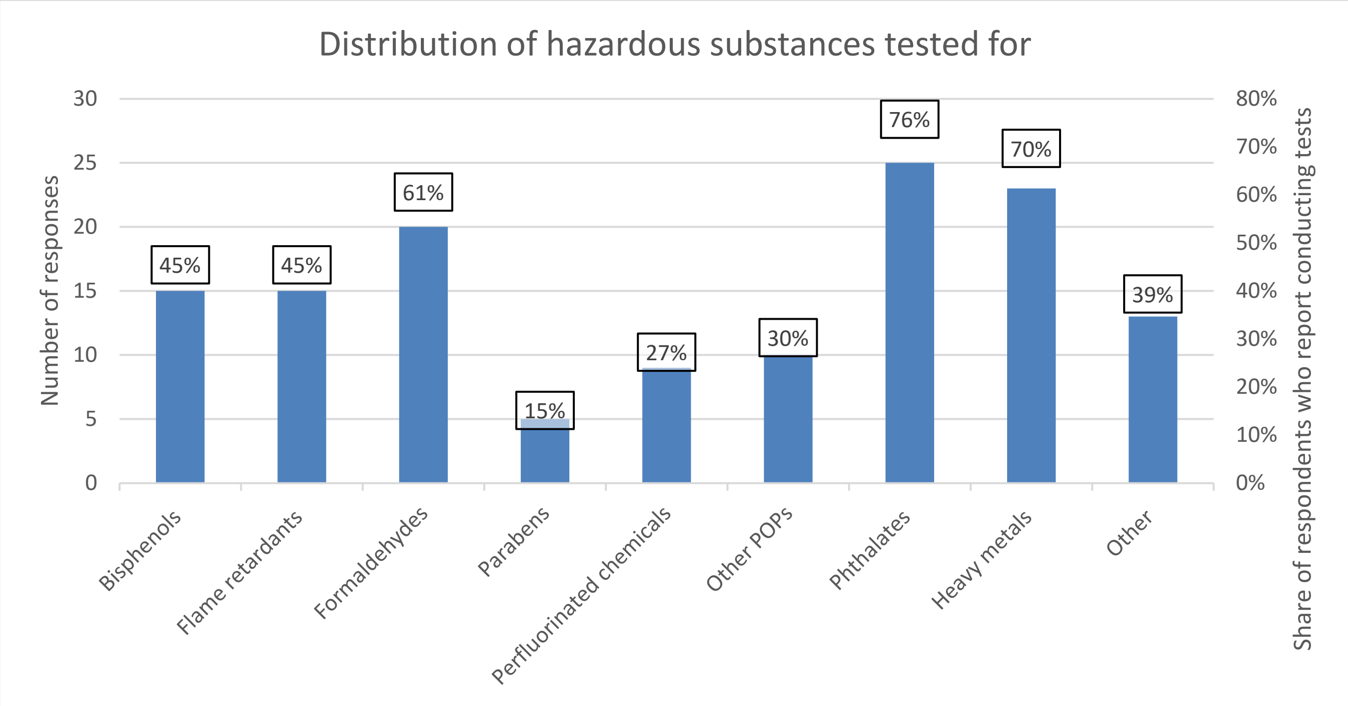

Figure 28: Hazardous substances tested for

Finally, respondents were asked to elaborate on their survey responses and any other thoughts they wished to communicate. From these responses, two key themes emerged:

- Toy manufacturers and retailers indicated that the use of recycled plastic is rare, impractical or in many cases impossible in toys. This is due to both the unreliability of recyclate for high-end toys, but also because it is “simply impossible to control the chemical content tightly enough”.

The unreliability of recyclate and inconsistency between batches was highlighted as a crucial limiting factor for some respondents. It would require much more regular spot-testing to ensure regulatory adherence, as opposed to testing the first batch from a supplier.

1.1.1.30 Reprocessor survey

1.1.1.30.1 Respondent profile and recycling practices

There were nine respondents to the reprocessor survey. Of these, six (67%) were based inside the UK, with three (33%) based outside the UK. The respondents took in primarily textile waste (57%), plastic waste (29%) and paper & cardboard waste (14%); this means that no respondents taking waste electronics (WEEE) or mixed household waste participated in the survey. Given the importance of WEEE recycling indicated in the review of published literature (see section 2.1), the lack of WEEE reprocessor is a particular limitation.

Respondents indicated a broad range of sources for their feedstock including retail, manufacturing and construction industries, as well as from Local Authority sources or post-consumer waste.

The majority (67%) indicated that they perceive a difference in UK and non-UK sourced RC. This is a notable contrast to manufacturers and retailers, where the majority (68%) indicated that they do *not* perceive a difference in UK and non-UK sourced recycled content. The small number of responses from reprocessors mean this result must be caveated by a lack of confidence, but the contrast identified here may suggest varying opinions based on the sector. The main reasons cited by reprocessors for those differences were traceability and capacity: they suggest that UK sources are more easily verified, whereas imported is not. In the case of textile reprocessing, the UK lacks the capacity for production, and this was highlighted as a difference: circular textile raw materials produced in the UK need to be exported.

Respondents were asked about sorting and filtering methods, but no clear trend identified any one method as being more popular than others.

Respondents were also asked about performance specifications: the key themes emerging were that their recycled material must offer equivalent performance and qualities to the virgin or 'standard' materials used, and that it must meet specific grades or specifications, such as being fibre-grade polyester, or meeting particular specifications the purchaser has outlined.

1.1.1.30.2 **Regulations and chemical testing**

When asked about regulatory requirements, the most cited requirements were the REACH regulations. Some reprocessors indicated that the need to comply with REACH meant that the requirements upon using recycled content were the same as those for using virgin materials.

Due to high non-response rates, it is difficult to form conclusions from the remaining questions related to regulations and chemical testing. Less than half (40%) of respondents indicated that they test feedstock material. However, nearly half of respondents (44%) did not respond to the questions on testing. When asked about chemical groups tested for, the non-response rate was even higher, with only two respondents (22%) providing an answer. Subsequent questions on why things were tested similarly had non-response rates of over 50%.

As a result, it is difficult to draw any meaningful trends or results from the responses to these questions. It is unclear if the high non-response rate at this point reflected some bias in the questions encouraging respondents not to answer – particularly if their answers were going to be that testing does *not* occur, and they perceived that to be the 'wrong' answer – or if it reflects a general disengagement with the survey. A persistent non-response throughout and lower response rate in general does suggest that reprocessors were less engaged than manufacturer and retailers. This unfortunately limits the utility of the second survey and conclusions which can be drawn from it. As a result, the results are not detailed any further.

Discussion

Two surveys were carried out. Due to both the low number of respondents and then the high non-response rate on key questions about chemical safety and testing, unfortunately very limited meaningful conclusions can be drawn from the reprocessor survey.

Among manufacturers and retailers, some key conclusions centre around the high reported use of RC. The majority of respondents (79%) indicate that they do use RC, and the majority (76%) also indicate that they blend RC with virgin materials. RC use and blending is driven primarily by price and material quality, but the transparency and certification of RC was highlighted as an important factor in sourcing RC, including the guarantee that it adheres to regulatory requirements.

The reported awareness of regulatory limits was high, with both manufacturers and retailers and reprocessors regularly citing REACH chemical lists as the primary reference point. For manufacturers and retailers, the responses to the survey suggest a general expectation that chemical safety concerns should be dealt with upstream by suppliers and manufacturers, with certification of material testing being used to ensure regulatory compliance. There was a suggestion both that this is how manufacturers and retailers currently adhere to regulations, and that this was how it should be adhered to.

Confidence in current safety practices was a recurring theme: concerns about chemical safety were evenly split between those concerned and those not concerned, with those not concerned primarily citing confidence in the testing regimes, their suppliers and the certification currently undertaken. The reliability, reach and enforcement of regulations like REACH and standards including OEKO-TEX and EN 71-3 were recurring themes. There was some variation between product groups: clothes and textiles manufacturers and retailers showed slightly lower levels of concern, whereas electronics and toys manufacturers and retailers showed higher levels of concern. In particular, toy manufacturers and retailers used the survey as an opportunity to express the difficulty of using RC: one suggested it is “simply impossible to control the chemical content tightly enough”.

Overall, the surveys points towards an engagement both with the circular economy and chemical safety of products, and some confidence in precautions currently taken and the role of standards and regulations. The expectation is that those upstream, namely the supplier and manufacturer, have the responsibility of testing and certifying their materials, and that this is currently undertaken for a wide range of chemicals. These results must be caveated by the limited convenience sample: the type of manufacturers and retailers who are sufficiently engaged with WRAP may be more reputable, responsible businesses with a demonstrated interest in circular economy issues. It is unlikely to be representative of the wider industries, particularly the industries based far less in the UK. As a result, the results may bias towards showing a more positive image of manufacturer and retailer engagement than will be the case across the wider industries.

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In-depth telephone interviews

Introduction

In-depth interviews were held from each of the priority product categories (electronics. toys and soft furnishings) and the reprocessors. The intention was to conduct 3 interviews from each category i.e. 12 in total, however, 9 businesses in total were willing to be interviewed. Of those 9 interviewed, the breakdown was as follows:

- 3 retailers or manufactures of textiles goods only;
- 2 retailers or manufactures of toys only;
- 3 retailers or manufactures of toys and electronics; and
- 1 retailer or manufacture of both textiles and toys and electronics;

The aim of the interviews was to explore in greater detail the understanding of risks and barriers associated with the use of recycled materials, awareness of chemical thresholds and how they would manage these issues in relation to the use of recycled materials. The interviews also set out to corroborate some of the findings of the literature reviews and the online surveys conducted.

Context

It is worth summarising the supply chain set up of the businesses interviewed for context. The survey showed that for textiles, toys and electronics businesses, production was mostly based overseas with some businesses opting to produce both internationally and domestically.

The 3 businesses that sold textiles exclusively revealed their production took place mostly abroad (e.g. Estonia), though, one respondent identified that a small percentage of clothing was produced domestically.

One business in the toys and electronics sector based most of their manufacturing within the UK. In contrast to this, of the 2 businesses focusing on toys, one based its production exclusively in China, this was primarily due to the high labour costs associated with UK labour and China possessing specialist widget tools for manufacturing not found elsewhere.

The second toy manufacturer had various locations of production in Europe and China, stating the importance of geographical proximity of production close to the source material to reduce the length of the supply chain.

Material sourcing and recycled content use

Most businesses sourced their raw materials abroad, with common locations including parts of Eastern Asia including Bangladesh, China, India and South Korea. Other locations included Mexico, as well as some European countries such as the Netherlands and Germany.

Only the toys and electronics manufacturer sourced its materials from the UK.

Price was a significant factor in these decisions as it was not considered competitive to source materials from the UK.

Only the manufacturers of textiles reported using varying degrees of recycled content in products. The two toy manufacturers and those focusing on toys and electronics, stated they did not use recycled content in their products at all.

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Findings

It should be noted that, as qualitative research, the interviews were not designed to yield statistical results but to explore in greater detail and verify a number of the findings from the literature review and surveys.

1.1.1.31 Risk and Barriers

Interviewees highlighted a number of risks and barriers to using recycled materials. These included concern about potential toxicity issues for toys, traceability issues for electronics, availability of recycled content and regulatory concerns.

For those using recycled materials, the primary issues faced when sourcing recycled content related to the costs, traceability and even supply. Whilst cost was most often cited as a concern by textiles businesses, toy manufacturers highlighted the cost of recycled materials was up 44% against virgin materials in the past year.

As well as cost, textiles manufacturers cited quality as a significant issue, with high quality materials being difficult to source. Furthermore, supply was found to not meet demand leading to further price rises of recycled content as the price of oil decreased.

Businesses cited traceability as a key barrier with the origin of the recycled content often difficult to track. Manufacturers argued that a lack of certification of the recycled content meant the business could not make the claim on the packaging. In fact, one toy manufacturer went further to state it was not possible to guarantee authenticity of certificates of compliance in countries such as China and India and therefore the risk was too great.

Both toy manufacturers noted how the lack of availability of quality recycled content meant their businesses could not use recycled content at all, as it would be difficult to be certain whether imported recycled materials are fully compliant of safety regulations. The fact that Operation National Sword[11] had banned or severely restricted imports of recycled material to China since 2017 further exacerbated the issue as any recycled material in China is likely to be from domestic markets. One interviewee stated that, for example, their own testing of recyclable products has found trace elements of lead, cadmium, heavy metals and organic tin.

1.1.1.32 Regulatory Requirements

All businesses interviewed had good basic knowledge of regulations, with the majority stating REACH regulations as the minimum standards their products complied with, particularly in the textile sector. However, there were examples of textiles and toys and electronics businesses going above and beyond minimum requirements to meet additional regulations or setting strict internal requirements. This was also dictated by the sector served. For example, toys manufacturers complied with requirements dictated by EN71 Part 3, designed to assess the migration of certain chemicals, including heavy metals, into the body if a toy or components of a toy were to be swallowed by a child.

1.1.1.33 Testing for Hazardous Substances

The textiles businesses stated they did not test for hazard substances beyond what is required by the relevant standards and regulations, and were not concerned about

[11] *The **Operation National Sword** was a policy initiative launched in 2017 by the Government of China to monitor and more stringently review recyclable waste imports.*

the chemical safety of their products as their materials were all certified in line with relevant standards (e.g. Global Recycling Standard, OEKO TEX) or legal compliance with REACH.

Reiterating that the toys and electronics businesses did not use recycled content in their products other than packaging, these sectors had a more mixed approach to testing. 60% said they did conduct some form of testing for hazard substances or chemicals such as Bromates, whilst the remaining businesses from the electronics sector admitted they did not believe testing was required as they were confident the virgin materials they had used met regulations.

There was consensus in the toys and electronics sector that testing was very expensive with some businesses only testing for a limited range of substances e.g. Bromates.

However, the two manufacturers in the toys sector emphasised the industry is heavily regulated in terms of what raw materials can be used and the testing that must be undertaken to demonstrate compliance for a range of chemicals across several regulatory regimes. Even virgin raw materials are subjected to stringent and regular testing with batches often very close to threshold limits for contaminants such as heavy metals. This is compounded by the fact that different toys require different testing regimes according to the age group it is targeted towards. For example, testing of toys aimed at under 3 year olds or that could be placed in the mouth, is far more frequent.

Furthermore, one toy manufacturer emphasised that in order to ensure compliance with all global regulatory regimes e.g. USA and EU, the regulations setting the strictest chemical detection limits are used as a baseline across all products, with an additional maximum internal detection limit imposed across all products to allow for variations in detection limits and tolerances.

Lastly, the toy manufacturers were keen to highlight an additional barrier to incorporating recycled plastic, that of physical performance. Replacing parts of a toy made of a specific polymer such as ABS, that has been proven to function in certain conditions and achieve desired outcomes for decades is not straight forward.

Summary

The interviews validated what was reported in the online surveys. Traceability of materials was identified as a common concern across all groups interviewed. The groups interviewed highlighted different priority concerns related to the use of recycled materials. Whilst electronic and textile retailers and manufacturers were confident in the safety of materials used, toy retailers and manufacturers considered that hazardous content was a barrier to the use of recycled materials. Further quantitative research would be required to understand whether or not there is a significant difference between industry groups' concerns. Toy manufacturers have emphasised that they believe recycled plastic suppliers, particularly in countries such as China and India, cannot guarantee the original, consistency, traceability or regulatory compliance of recycled material. For this reason both toy manufacturers interviewed stated they did not wish to compromise the safety and quality of their products through the introduction of recycled materials.

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Stakeholder Workshops

Introduction

Following on from the in-depth interviews, selected businesses and trade organisations were invited to a workshop to review and sense check the findings from the previous phases. Delegates[12] views were sought to verify the results of the survey and interviews and to identify actions that would:

- increase understanding of chemical risks from recycled materials;
- minimise business risk in using recycled materials;
- improve technical or management actions (across the supply chain) to reduce risk;
- assign responsibility for ensuring risks are understood and accounted for in the priority sectors; and
- increase the overall use of recycled materials whilst avoiding a trade off against risk.

The workshop facilitated a ‘sense check’ of the initial findings from the interviews, tested the general trends identified and allowed for exploration of the more nuanced aspects regarding the use of recycled content. It also helped identify factors that may have been missed in interviews.

Findings

Increase understanding of physical/chemical risks from recycled materials

There was a unanimous message from the toy industry and its representatives that the high levels of safety gate reports associated with toys are due to the fact that toys are very high on the enforcement target lists, rather than that they are intrinsically more likely to be associated with risk.

The toy industry emphasised there is no distinction between ‘reputable’ and ‘non-reputable’ manufacturers[13] when reporting on safety breaches for chemicals such as phthalates and heavy metals. This therefore does not reflect the efforts the industry makes to comply with strict safety limits for toys. The industry has identified recently through its own in-house testing, a sharp increase in chemical breaches against UK and EU product safety standards in several toys sold by third party sellers from countries such as China and other non-EU countries[14] via a number of reputable online platforms.

Indeed, reiterating what was said in the in-depth interviews, this was cited as the main reason reputable toy manufacturers avoid the use of recycled material in toys despite the growing appetite within the industry. Representatives of the industry emphasised it is not currently possible to guarantee transparency and consistency within the supply chains of raw materials, unless virgin materials are used.

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[12] The workshop was advertised separately to prior stages of research. However, nobody was prevented from signing up, and so some organisations may have been present for both stages of research.

13 These were the terms used by participants in the stakeholder workshop. They are understood to represent, broadly, ‘reputable’ manufacturers and retailers: those who sell branded products, are members of industry trade associations and other bodies and so on and ‘non-‘ or ‘disreputable’ ones which sell unbranded, cheap products often imported and direct-to-consumer.

14 https://www.btha.co.uk/wp-content/uploads/2020/10/Report-BTHA-Toy-Safety-Campaign.pdf

Furthermore, even when virgin materials are used, extensive testing is undertaken as often extremely stringent limits on chemicals such as phthalates and heavy metals are also exceeded or often at the threshold of detection.

Representatives from both the electronics and toys industries agreed that given the prominence of the toy manufacturing industry in countries such as China, there was an over emphasis by many authors of the safety gate reports and literature studies on one or two contaminants from a select number of toys, such as Bromates and phthalates, without delving into the origins of these contaminants. For example, is the source of the plastic feedstock from waste electronic sources? If so, is there an indication of how old this feedstock is as regulations for electronic items manufactured decades ago have become far more stringent on threshold limits. What is the origin of manufacture and what is the recycling infrastructure like in the country of collection and reprocessing? Questions were raised on whether this minority number of results were negatively skewing the reality and would these be influenced if these parameters were eliminated and the results re-evaluated.

The industry emphasised that UK recycling infrastructure for electronic waste was far more stringent and governed by the WEEE Regulations and Hazardous Waste Regulations amongst others. This means items deemed to contain persistent organic pollutants are separated out from the remaining stream and sent to Energy from Waste or incineration.

However, the fact there are no boundaries with movements of materials means identifying origin of manufacture and whether it originates from a reputable manufacturer is the industry’s biggest challenge.

Minimise business risks in using recycled materials and improve technical or management actions across supply chain to reduce risk

There was consensus from attendees in the toy industry that the risks to business reputation of using recycled content was far too high for a number of reasons. The longevity of some items before being disposed of or recycled means they may have been manufactured 10-15 years ago, when legislation on detection limits and contaminants was less stringent.

Therefore there is a greater risk of breaches in detection limits, or even banned substances being present due to legacy contaminants still circulating. This is an issue that was identified in the literature research as a major concern and source of contaminants such as flame retardants arising from electronic items manufactured at a time when these additives were permitted. The longevity of such items means there is a lag between legislation banning materials and items appearing in the recycling or waste stream. This issue and a potential solution is further discussed in the section below on how to *Increase the overall use of recycled materials whilst avoiding a trade-off against risk.*

In addition, the ban of and stringent restrictions on waste/ recycled material imports by China during Operation National Sword in 2017 has meant that there is very little recycled content to be used in such products. Any recycled material available is likely to be from Chinese domestic markets and manufacturers and retailers were uncertain of the quality of materials available.

There was also concern from the textiles industry regarding the lack of mandatory certification schemes for recycled fibres. Although the Global Recycling Standard sets standards for third party certification of recycled products, it is only a voluntary scheme and therefore not universally adopted by the industry. This cast a doubt on the traceability and certification of the scheme. This concern of enforcement was also raised by the toy industry during the in-depth interviews where the majority of manufacture occurs in countries outside of the EU and where standards of enforcement are reportedly less stringent.

Assign responsibility for ensuring risks are understood and accounted for in the priority sectors

Similar to the in-depth interviews, it was agreed that the manufacture was overall responsible for the risks posed from using recycled content in products. However, there was some clarification from attendees to reiterate the fact that own brand retailers were classed as the manufacturer and therefore also responsible for the risks.

Increase the overall use of recycled materials whilst avoiding a trade-off against risk

Increasing the use of recycled materials, particularly within the toys sector remains a real challenge despite an appetite and willingness from the sector. The enforcement of current voluntary standards was discussed as a possible tool as was the incoming Plastics Packaging Tax which was seen to be a positive addition. However, given the plethora of regulations and mandatory stringent standards already in place governing toy manufacturing, it was felt that adding more would not add value. The industry undertakes its own internal testing in addition to mandatory requirements. Attendees stressed that those manufacturers willing to comply do so already and this distinguishes the reputable manufacturers from the non-reputable ones.

A lack of clean and consistent feedstock was raised as the biggest barrier and the issue of legacy contaminants because of the difficulty in knowing when and where toys were manufactured. This is exacerbated by the way toys are usually disposed. Smaller items tend to be discarded in the household recycling stream whereas larger items are collected at household recycling centres with other mixed rigids. This can include items such as PVC window frames, furniture and other unknown items and therefore separating single clean polymer streams is uneconomical and challenging.

The issues of consistency raises an interesting point which could be further explored: if manufacturers have one sample tested, what assurance would they need to undergo to ensure every batch is as compliant as that initial ‘golden sample? This inconsistency is currently a barrier to using recycled content.

Reiterating what was highlighted in the in-depth interviews, food grade material, is considered the best option for the industry to increase its use of recycled plastic. However, the challenge lies with sourcing suitable quantities of this material which is in very high demand by the food sector and major food and beverage brands in order to meet their targets. Chemical recycling was discussed as a possible solution going forward as a way to create a level playing field for the recycling industry. However, a representative from the chemical recycling industry emphasised this technology was still in its infancy and it would be 5-10 years before enough capacity was developed to satisfy the industry’s needs. There are also limits to what feedstock can be accepted for chemical recycling dependant on the technology, e.g. PVC is not always accepted, which added to the demand for polymers such as PET.

Areas for future research

Based on the key themes, findings and conclusions of this scoping study (see the Executive summary for an abridged version of the findings, or the tables in section 2.1.2), some key data gaps for future research have been identified.

Bridging the gap to human health risk

There is sufficient evidence of the presence of focus analytes in some product groups, including chemicals which are believed to be in the product as the result of use of recycled content. This is particularly well-evidenced with regards to flame retardants and associated heavy metals from WEEE. However, a substantial data gap remains in terms of bridging the presence of chemicals in consumer products which may use recycled materials with the risks posed to consumers. Most papers use legal limits as a form of proxy, but these limits may change in future. The main research question for this study (see 1.1) centred around human health risk. The current information is insufficient for answering this conclusively.

Many of the believed-recycled materials which were identified as having harmful chemicals had substantial variability in the chemical concentration. Often, the chemicals were detected in very low concentrations. However, as they may be found in unexpected items, exposure to these chemicals through these routes could be an unexpected, additional route of exposure to those considered ‘normal’. Only a small handful of papers (See, for example, S.-J. Chen et al., 2009 and; Fatunsin et al., 2020) calculated exposure risk to these recycled chemicals in normal use. In the literature, focus has been paid in particular to products used by children and infants, because these are vulnerable groups who interact with products in ways which may increase their risk profile, but also because of the particular emotive importance of children’s health. Broadly speaking, most migration tests fell within acceptable risk ranges. However, more work to calculate these exposure risks for a wider population and compare and combine them with other routes of exposure that present possible risk from additive exposure (occupational, dietary etc.) is necessary to get a more complete image of consumer health. In particular, comparisons of health risks between recycled content contamination at low levels and purposeful addition of harmful additives, such as those reported on the EU Safety Gate portal, will help policymakers and regulators to identify priority areas of concern.

Counteracting possible literature biases

As has been detailed in regards to the limitations of this study (see section 2.1.5.4), systematic biases identified in the literature may undermine conclusions drawn in this review. Three main biases were identified: positive results bias, political saliency bias and methodological biases. It is important that these are counteracted to identify if some chemical health risks have been systematically overlooked, and future research should be geared towards this. In particular, the nature of the possible risk posed by use of recycled content is that chemicals may emerge where they are not expected to be found. The nature of the biases identified may disincentivise academic researchers from ‘testing the unexpected’ because of funding constraints limiting access to suitable methodologies, a pressure to publish positive results, and less interest in findings related to particular products, chemicals or groups exposed to the risk. It could be a fruitful avenue for regulators or governmental research to research and transparently report on the results of systematic product tests, including tests for unexpected materials. The distribution of negative and positive results identified through more comprehensive testing would offer justification and confidence in future decisions to target particular chemicals and product groups.

A number of areas which are considered particularly notable data gaps are listed below. These would benefit from further research:

- Cosmetics packaging was a product for which information was not identified. As some cosmetics and toiletries now advertise having recycled content in their packaging, targeted testing could identify the presence and risks of possibly unexpected contaminants, helping to determine whether it is a category of concern or not.
- Parabens, formaldehydes and other persistent organic pollutants (not classified into another chemical group) were not identified in approximately half of our focus product categories. It is unclear whether this is due to an absence of these chemicals or reflects biases in the testing. Systematic testing would help to inform this.
- The use of recycled plastic in polyester fibres was raised as a possible source of BPA, but the findings were inconclusive. Given the frequency of use of recycled plastics in garments, further verification to identify the differences between recycled and non-recycled polyester would be valuable.
- Motor vehicle parts were shown to have substantial concentrations of flame retardants, including in waste vehicle parts (see 2.1.4.2.7). However, the evidence identified pertaining to the recycling process and use of plastics in new products focuses overwhelmingly on WEEE recycling (see 2.1.4.3). The risk of flame retardants in waste vehicle parts depends on how that waste is treated and, if recycled, what it is recycled into. Understanding whether, where and into what products ELV is recycled is a current data gap.
- Toys were identified as being a product group with a substantial amount of evidence that WEEE could be being recycled into new products (see 2.1.4.2.5). However, as was identified by stakeholders (see 4.0), an analytical distinction can be made between ‘reputable’ and ‘disreputable’ industry. Generally, academic studies into chemical concentrations in toys made little distinction between the origins of those products. Further research which make this distinction, comparing origin both by country and type of business, would help in understanding how widespread the issue is and whether it is concentrated in certain business or manufacturing countries.

Expanding the scope of chemical groups

Related to the data gaps identified through literature biases, this report has the limitation of being an initial scoping study, which may have led to some chemicals or products being overlooked. It was not intended to offer an exhaustive overview of possible chemical issues, with a scope defined at the outset of the project (see 1.3). This scope may have overlooked other chemicals which could persist through recycling, or indeed other products, such as the black plastic household items identified in some studies (see Table 9). Some review papers identified through the course of this study could offer fruitful avenues for understanding where to target any subsequent expansions of scope for specific materials. For example, the comprehensive study by the Danish EPA presented in section 2.1.4.3.1 details a large number of hazardous substances found in plastics, including estimation of consumer exposure risk and fate of the substance by recycling, based on the types of plastics in which the compounds are used and their characteristics under mechanical recycling (Hansen et al., 2014). This could serve as a starting point regarding plastics, facilitating targeted examination of the chemicals they consider most likely to persist through recycling and the material types in which they are found. In a similar vein, other analytes such as nanoparticles, quinoline, benzothiazoles, benzotriazoles and aromatic amines came up in a review paper of additives in textiles (see 2.1.4.2.2 or (Rovira & Domingo, 2019)). Examining recycled textiles with a focus on such substances could offer another starting point.

Focusing on material rather than product

The evidence identified in this study suggests that known chemical risks associated with recycling are particularly tied to the recycling of e-waste. Plastics, in particular those used in electronic housings such as ABS, may therefore be of particular concern. The evidence suggests that recycled e-waste can emerge in a range of items: plastic toys, fashion accessories or plastic jewellery, new electronics, and some products which fell out of our category scopes such as office equipment and food-contact kitchen items. As was highlighted in some studies, black plastic is of particular concern.

There is a risk that taking a product-based approach may lead to data gaps as other products are overlooked. Within this study, possibly relevant data for product groups not within scope were identified (see Table 9) which corroborate findings elsewhere that black plastic items are a particular outlet for recycled WEEE (2.1.4.1.2), and a systematic search for such evidence could possibly identify more. To counteract this, it would be beneficial for future research to follow the lead that some authors have taken in looking cross-products based on the materials they contain. This would allow for more targeted testing of a particular recycling-based contamination pathway, if one had been identified, such as e-waste in black plastics. Future research being designed this way could avoid creating future data gaps and contribute to answering our primary research question.

The creation of a common reporting for evidence of product contamination

As identified throughout the literature review (see 2.1), the evidence of contamination of product samples is disparate, spread across numerous academic and governmental studies which offer varying levels of detail, scopes of analysis and frame of reference. There is not, to our knowledge, a repository for such data to be captured and compared. As a result, comparisons of specific product samples and their chemical concentrations is difficult: some authors report isolated products, others aggregated groups, for example. The initiation of such a common repository could be a fruitful avenue to pursue, such as through the creation of a collaborative database of anomalous results which could be considered evidence of recycling-based contamination. By reporting information on samples and concentrations of certain chemicals to one standard or in one place, it would become easier for researchers and consumers to understand the scale of the problem. For example, given the evidence presented here for e-waste recycling into plastic products, particularly black plastic products, as being of notable concern, a mechanism for standardised reporting of plastic samples with variable, low levels of flame retardants and associated heavy metals could be beneficial. This would allow for easier comparisons of the types of materials, products, colours, origin, presence of restricted chemicals etc. This beyond the scope of this initial scoping study, but the evidence identified here could form a useful starting point.

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Project outcomes against research questions

As identified in the project background and aims (see section 1.0), a set of research questions were set out to structure this project. As a scoping study, it was known from the outset that these questions could possibly not all be answered fully, and that the research process would be iterative in which the specific aims are in part shaped by the findings.

This section discusses those initial research questions and the extent to which they were answered. It also addresses some limitations, possible improvements and data gaps which have been identified in the areas for future research (see 5.0).

Primary question:

- *What are the potential physical and chemical safety concerns relating to the use of recycled materials when compared with virgin materials in consumer products and associated user exposure risks?*

The initial primary question was about both physical and chemical safety risks, but as the research progressed, the research question evolved and chemical risks became the primary focus (as in the final research question, section 1.3). This was done for a number of reasons based on how the project progressed:

- More evidence was identified relating to chemical risks of materials and products, both recycled and not, than to physical risks, from existing experience, initial searches and evidence identified;
- From the research team's experience in working with companies to increase use of recycled content, it was judged that physical quality issues are to some extent self-regulated: if recycled content changes the quality and functionality of the material as used in the products to an unacceptable level, it will not be used. This was verified by stakeholders in both the surveys (see 3.1) and interview process (see 3.2). For example, quality/physical integrity issues were listed as one of the main reasons for *not* using recycled content (Figure 17), with quality of material one of the main factors considered when sourcing recycled material (Figure 18). Manufacturers therefore only use recycled content where these physical quality issues are minimised. However, this does not preclude physical risks from the use of recycled content where its presence was not necessarily known to the manufacturer, or for those with less robust standards. As indicated through the literature review (see 2.1.4.3 for evidence of recycling of WEEE plastics), some plastic recycling in countries with substantial manufacturing bases is informal and unregulated, and manufacturers may not knowingly be purchasing recycled plastics. Similarly, a difference between 'reputable' and 'non-reputable' manufacturers and sellers, as highlighted by workshop attendees (see 4.0), may be reflected in physical risks: whilst 'reputable' manufacturers may avoid use of recycled content where physical qualities are changed, this may be less likely for manufacturers of unbranded, cheap consumer goods. There was no evidence identified about this, but it may constitute a fruitful avenue for future research;
- Whilst there is research into the physical properties of recycled materials compared to non-recycled materials (see, for example: Demets et al., 2021), the research question was focused explicitly on consumer products. Information bridging the gap from physical properties in materials to physical risks in products would be needed.

Based on the above, it was determined that chemicals in recycled products are likely to pose a more substantial risk. Focus was therefore given to chemical risks. As a result, the primary question can be said to be in part unsuccessfully addressed.

For chemical risks, the project was able to partly answer the research question, but also highlighted substantial evidence gaps in attempting to do so. Potential safety concerns through the use of recycled materials were explored in the literature review (see 2.1) through evidence of the presence of regulated chemicals in products. However, overall this evidence was inconclusive to compare recycled and virgin materials, as in many cases the presence of these chemicals was not clearly associated with the use of recycled content, but was due to purposeful addition of these chemicals. The evidence for recycled content was largely inference rather than observation. The primary exception is the use of recycled plastics from e-waste containing brominated flame retardants and associated heavy metals such as antimony: their presence in plastics, particularly black plastics, may be constituted a potential chemical safety concern from the use of recycled materials.

However evidence of user exposure risks to these chemicals is less widespread and robust, with few studies examining risks to consumers directly from use of the product with a potential chemical risk. Therefore, this part of the question cannot be said to be fully answered, largely due to evidence gaps.

Secondary questions:

- *What are manufacturer's responsibilities when using recycled materials in products?*

Relevant legislation and standards for the product groups in scope have been identified (see 0). However, in product safety legislation the recycled material is not considered differently to any other material used in a product. The stakeholder survey (see 3.1) also offers an indication of perceptions of these responsibilities, such as where in the supply chain responsibility is perceived to lie. This research question can be considered to be largely answered.

- *What is the application and extent of users of recycled materials in consumer products?*

The extent of use of recycled materials was partly indicated by respondents to the survey and interviews (see 3.0), with the majority of respondents indicating that they do use recycled materials. However, due to the convenience sample this is not indicative of the overall use of recycled content. The issue of contamination of cheap products with recycled plastic, possibly unbeknown to the manufacturer, also complicates the issue. As a result, accurate quantification of recycled content use is not possible. This research question can be considered partly answered.

- *What are the differences in the chemical makeup of products originating from within the European Union (EU) and those from outside the EU?*

The evidence identified in the analysis of Safety Gate (see 2.3) provides some evidence to suggest that chemical risks are more likely when coming from countries outside the United Kingdom and EU. The bulk of safety alerts identified were for products with origins outside the EU, particularly China. However, this data is presented with caveats: the relative distribution of alerts may simply be reflective of the relative distribution of manufacturing, with those countries which export the most products also having the most safety alerts associated with them. Secondly, whilst this gives an indication to differences in chemical makeup, the data presents nothing which would indicate that the cause of the difference is due to the inclusion of recycled content. However, evidence identified through the literature review (see 2.1.4.3) suggests that the recycling of plastics with restricted chemicals, such as brominated flame retardants, may be more likely in countries outside of Europe to which e-waste is exported. In places where recycling is less formalised, there is evidence that the incentives do not sufficiently encourage sorting and disposal of brominated plastics. When coupled with large manufacturing capacities in the same countries, there is the suggestion that there may be increased risk of recycled content with restricted chemicals entering new products. As a result, this research question can be considered partly answered.

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