Toxics in Carpets in the European Union

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Anthesis Consulting Group

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Executive summary

Introduction

On 18th October 2017, the Healthy Building Network with support from Changing Markets and the Global Alliance for Incinerator Alternatives, published the report: "Eliminating Toxics in Carpet: Lessons for the Future of Recycling" looking at the use of chemical additives in carpet manufacture, and their impact on human health and carpet recyclability.

This study carried out by Anthesis Group, builds upon that carried out for the US, and adapts it to the European market both in terms of market practices and regulation. This study is designed to give an overview of the most worrying chemicals used in carpets currently sold into the European market and the impacts of these chemicals on human and environment health as well as the transition to the circular economy. This study investigates how these chemicals are viewed in the current regulatory framework and certification schemes, and actions that can be taken for their elimination or replacement in transition to the circular economy. This study lays out extensive detail on the extent of the European carpets market and chemical additives used in manufacture for that market, whilst developing pertinent recommendations for regulators, manufacturers and consumers.

Summary

The EU is the second biggest market in the world for carpet after the US, as well as being one of the largest producers. The demand for carpets in the EU amounts to almost 1.8 million tonnes (Mt) per year, while around 1.6 Mt arises per year as waste. Of the waste carpet arising in the EU each year, the vast majority is likely to be landfilled, a large proportion incinerated, and only a few percent recycled. Several barriers exist to the recycling of carpets including carpet design, collection, contamination, and the presence of toxic substances. The focus of this report is to look at the toxic substances currently found in carpets and how these could be replaced and/or eliminated to facilitate the circular economy.

> ". . . the total environmental BoD [Burden of Disease] costs [from exposure to environmental chemicals such as neurotoxicants, air pollution, and endocrine disruptors] likely exceed 10% of the global GDP [e.g., $10.75 trillion]. . . the data presented suggest that environmental chemicals need to be more highly prioritized."
> *- Philippe Grandjean and Martine Bellanger Environmental Health (2017)* [149], [330]

In order to achieve more recyclable and less toxic carpets at scale, market transformation is needed. This report has identified a list of 59+ toxic substances used in carpets sold on the EU market. This list of substances includes phthalates, perfluorinated compounds (PFASs), flame retardants and toxic heavy metals. Based on the research, it appears many of the chemicals found in carpets may volatilize and/or migrate from carpets through typical use and abrasion of carpet as well as adhere to dust – making dermal, inhalation, and ingestion exposure to their toxic effects all possible.

Some of the toxic effects of the chemicals of concern identified in this report include carcinogenicity, mutagenicity, reproductive toxicity, and endocrine disruption just to name a few. Moreover, children are particularly vulnerable to these toxic chemicals, particularly during critical stages in their physical and cognitive development. Of the 59 substances identified in this report, 37 are not restricted or banned for their use in carpet or carpet materials. Additionally, many of the certifications that monitor chemicals in carpets do not currently ban or restrict the chemicals of concern in this report either. For example, the GUT label only bans or restricts 13 out of the 59 identified chemicals of concern.

There are ‘hidden costs’ associated with the use and exposure to chemicals of identified in this report. Health care costs and lost earnings linked to the exposure to endocrine disruptors is estimated to be €163 billion each year [1], [2]. There are also hidden costs associated with environmental contamination such as necessary infrastructure for cleanup. Industry is therefore often not responsive to the true costs associated with toxic chemicals and/or the products they create [3] and these costs typically are passed onto tax payers.

As a result of our research and findings, recommendations have been prepared for policy makers, carpet manufacturers, carpet certifiers, as well as consumers to ensure the highest level of consumer and environmental protection in the manufacture and use of carpets. These recommendations come at a critical time, as the European Union is reviewing legislation on the interface between chemical, waste and product legislation.

Key policy recommendations

Ensure an integrated health approach to the circular economy: More works needs to be done under REACH and related Directives to support a non-toxic circular economy. Part of this work needs to address the short comings of REACH, which would include solutions to optimizing the identification, evaluation, restriction and/or ban on chemicals of concern. Ensuring an integrated health approach to the circular economy would include carpets designed with a non-toxic circular economy in mind. Ensuring this type of integration requires the collaboration of multiple stakeholders across the industry. For the carpet industry, it means all actors in the supply chain working towards the common goal of facilitating transparency as well as scaling up non-toxic solutions to new carpet designs.

Identify and restrict/remove chemicals of concern in carpets: The 59+ chemicals of concern identified in this report as used in carpets sold on the EU market, should be restricted and/or banned to ensure consumer safety, environmental protection and facilitate the circular economy. The use of these substances is not limited to carpets, so in order to give adequate protection it is recommended to restrict and/or ban them via the REACH regulation. The process of identifying and evaluating chemicals of potential concern under REACH is often lengthy and efficiencies are needed to drive these processes along to ensure these substances are quickly and adequately restricted or banned. The continued use of chemicals of concern has negative implications on human and/or environmental health as well as impeding recycling efforts. Additionally, where the existence of a ban or limit exists for a chemical of concern in virgin materials, the same limit should exist for recycled materials, as some restrictions currently allow for higher concentrations of hazardous chemicals in recycled materials.

The report also concludes that REACH is not sufficient to manage chemicals found in carpet on its own. Because many people are exposed to the toxics in carpets across its life cycle, other regulations are needed to protect workers, environment, and consumers, especially the most vulnerable ones, such as children. Therefore, Directives that help mitigate these issues should be created and/or strengthened.

Extended Producer Responsibility and carpet specific legislation: There is growing support for EPR systems for carpets, mattresses, and furniture within the EU. It is recommended that, as the EU Circular Economy Package requirements are finalised and transitioned into law in each of the participating countries, Member States consider the introduction of an obligatory EPR scheme for carpet to cover the costs of responsible end-of-life management options and use modulated fees to incentivize recyclable, reusable and toxic-free carpet. This may lend itself toward a “Carpet Directive” similar to those that exist for packaging, WEEE etc.

Re-introduce an ambitious EU eco-label for textile floor coverings: As stated above, it is recommended that a minimum set of regulatory requirements governing chemicals, design, and EPR be put in place for carpets. It is recommended that the EU re-introduce an ambitious EU eco-label for textile floor coverings. The re-introduction of an EU eco-label for textile floor coverings would limit or ban all chemicals of concern in virgin and recycled materials and include the 59 substances identified in this report. Additionally, the EU eco-label would establish a set of robust design criteria so carpets can be recycled at the end of life. The criteria should go above and beyond any regulatory requirements.

Key manufacturing recommendations
Remove chemicals of concern from carpets: While regulatory processes are put into motion as they are necessary, manufacturers should take immediate action to phase these toxics out to keep credibility and ensure consumer safety. Industry should avoid the use of PVC as well as the substances identified in Appendix I in this report. Chemicals of concern should also be phased out from their use in carpets. In rare cases where safer alternatives do not exist, these carpets should be phased out or new technologies sought. Incoming recycled content should be tested to avoid high concentrations of toxic legacy chemicals.

Promote eco-design: Design carpets with the circular economy in mind – less toxic and recyclable. Use single fibre materials to increase recovery and recyclability. Make carpet backing from same material as face fibre, or easily separable. Avoid the use of SBR binders and bitumen as they provide a barrier to recycling and replace with non-toxic adhesives which allow easy separation of face and backing fibres. Do not use PVC as the chemicals used in its manufacturer are particularly toxic and contribute to a toxic circular economy. Additionally, avoid the use PFASs, antimicrobials, and flame retardants as safer alternatives exist to achieve the same function as these toxic substances. Where possible, avoid all other chemicals of concern.

Key carpet certification recommendations:
Expand the list of restricted chemicals: This report concluded that each certification scheme is failing to identify and restrict/ban chemicals of concern in carpets. These certification schemes may be misleading to consumers who believe their carpets are void of toxic substances or have the highest degree of safety. The Blue Angel eco-label currently does the best job in addressing chemicals of concern in carpets as it restricts or bans 51 out of the 59 substances identified in Appendix II of this report. Furthermore, all substances identified in Appendix II of this report should be restricted/banned by all certification schemes that certify carpet. Additionally, these certification schemes should go further to phase out the use of other chemicals of concern, ban the use of phthalates and PVC, as well as avoid the use of biocides and toxic flame retardants. Certification schemes must act fast to maintain credibility with the consumers.

Set complementary eco-design requirements for obtaining certification for carpets: Certification requirements should restrict/ban the use of chemicals of concern as well as those chemicals identified in Appendix II of this report in the use of carpet fibres, carpet materials, and any carpet treatments. Additionally, certification should favor materials that require the least number of chemical additives as well as set design criteria so carpets can be recycled at the end of life through take-back programs.

Key consumer recommendations:
Look for the Blue Angel or Nordic Swan eco-labels: The Blue Angel eco-label currently places the strictest chemical requirements on carpet manufacturers as it bans/limits 51 out of the 59 chemicals in Appendix II, with the Nordic Swan eco-label as a close second as it bans/limits 49 out 59.

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Abbreviations

Acronym	Definition
4-PCH	4-Phenylcyclohezene
APE	Alkylphenol Ethoxylates
ASE	Alkylsulphonic Phenyl Ester
BBP	Benzyl butyl phthalate
BNA	2-bromo-4,6-dinitroaniline
BOM	Bill of Materials
BOS	Bill of Substances
BPR	Biocidal Products Regulation
CE	Circular Economy
CLP	Classification, Labelling and Packaging
CMR	Carcinogenic, Mutagenic and Reproductive
CoRAP	Community Rolling Action Plan
DBP	Dibutyl phthalate
DBT	Dibutyltin
DEHP	Bis(2-ethylhexyl) Phthalate
DIDP	Diisodecyl Phthalate
DINP	Diisononyl Phthalate
DMIT	Dimethyltin
DNOP	Di-n-octyl Phthalate
DOT	Dioctyltin
ECHA	European Chemicals Agency
EEB	European Environmental Bureau
EFTA	European Free Trade Area
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
GPSD	General Product Safety Directive
GRS	Global Recycled Standard
GUT	Gemeinschaft Umweltfreundlicher Teppichboden
HCN	Hydrogen Cyanide
HEAL	Health and Environment Alliance
HMW	High Molecular Weight
IPBC	3-iodo-2-propynyl Butylcarbamate
IPTP	Isopropylated Triphenyl Phosphate
Kg	Kilogram
Kt	Kiloton (thousand tonnes)
LMW	Low Molecular Weight
LOC	Level of Concern
MDI	Methylene Diphenyl Diisocyanate
MSC	Member State Committee

Acronym	Definition
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
Mt	Million Tonnes
NFPA	National Fire Protection Agency
NP	Nonylphenols
NPE	Nonylphenol Ethoxylates
OBPA	10'-Oxybisphenoxarsine
OELs	Occupational Exposure Limits
PA	Polyamide
PACT	The Public Activities Coordination Tool
PAH	Polycyclic Aromatic Hydrocarbons
PBDE	Polybrominated Diphenyl Ethers
PBT	Persistent, Bioaccumulate and Toxic
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofurans
PET/PE/PES	Polyethylene Terephthalate/Polyester
PFASs	Perfluoroalkyl Substances
PFC	Perfluorinated Compounds
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonic Acid
PP	Polypropylene
PPM	Parts Per Million
POPs	Persistent Organic Pollutants
PTT	Polytrimethylene Terephthalate
POTW	Publicly Owned Treatment Works
PU	Polyurethane
PVC	Polyvinyl Chloride
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio Frequency Identification Devices
RoHS	Restriction of Hazardous Substances
ROI	Registry of Intentions
RMOA	Risk Management Option Analysis
SB	Styrene Butadiene
SBR	Styrene Butadiene Rubber
SUD	Safe Use Determination
SVHC	Substances of Very High Concern
TBT	Tributyltin
TCEP	Tris-(2-chloroethyl) Phosphate
TCP	Tricresyl Phosphate
TCPP	Tris(1,3-dichloro-2-propyl) Phosphate
TDI	Toluene Diisocyanate
TeBT	Tetrabutyltin

Acronym	Definition
TSD	Toy Substance Directive
TPP	Triphenyl Phosphate
TXIB	1-isopropyl-2,2-Dimethyltrimethylene Diisobutyrate
UAE	United Arab Emirates
US	United States of America
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compounds
vPvB	Very Persistent Very Bioaccumulative
WEEE	Waste Electrical and Electronic Equipment
WFD	Waste Framework Directive
WHO	World Health Organisation
WRAP	Waste & Resources Action Programme
ZPT	Zinc Pyrithione

Glossary

Term	Definition
Actors	A participant in an action or process.
Bioaccumulate	A substance that can become concentrated inside the bodies of living things.
Biocide	Defined in the European EU legislation as a chemical substance or microorganism intended to destroy, deter, render harmless, or exert a controlling effect on any harmful organism by chemical or biological means.
Broadloom	The production of carpet on a wide loom, producing large rolls.
Carcinogen	A substance capable of causing cancer in living tissue.
Chemicals of Concern	For this study, is defined as category 1 and category 2 CMRs (Carcinogenic, Mutagenic and Reproductive substances), endocrine disruptors and other substances of equivalent concern.
Circular economy	A circular economy is where resources are kept for as long as possible, extracting the maximum value from it during its use phase, products can then be recovered and regenerated at the end of each service life. It's seen as an alternative to a traditional linear economy.
Contamination	The action of making something impure by polluting.
Depolymerisation	The bonds between monomer residues in the plastic are broken either chemically (hydrolysis or glycolysis), or thermally, generating monomer species which can be used in raw material production – these processes can also be referred to as monomerization.
Downcycle	To reuse a product or material in such a way as to create a product of lower quality than the original.
Energy from waste	Waste-to-energy or energy-from-waste is the process of generating energy in the form of electricity and/or heat from the primary treatment of waste
Face yarn	The top layer of a carpet that is typically made of yarns that are tufted or woven.
Flame retardant	Flame retardants are chemicals added to materials to slow or prevent the start or growth of fire.
Halogenated substances	A volatile compound containing halogens such as chlorine, fluorine or bromine.

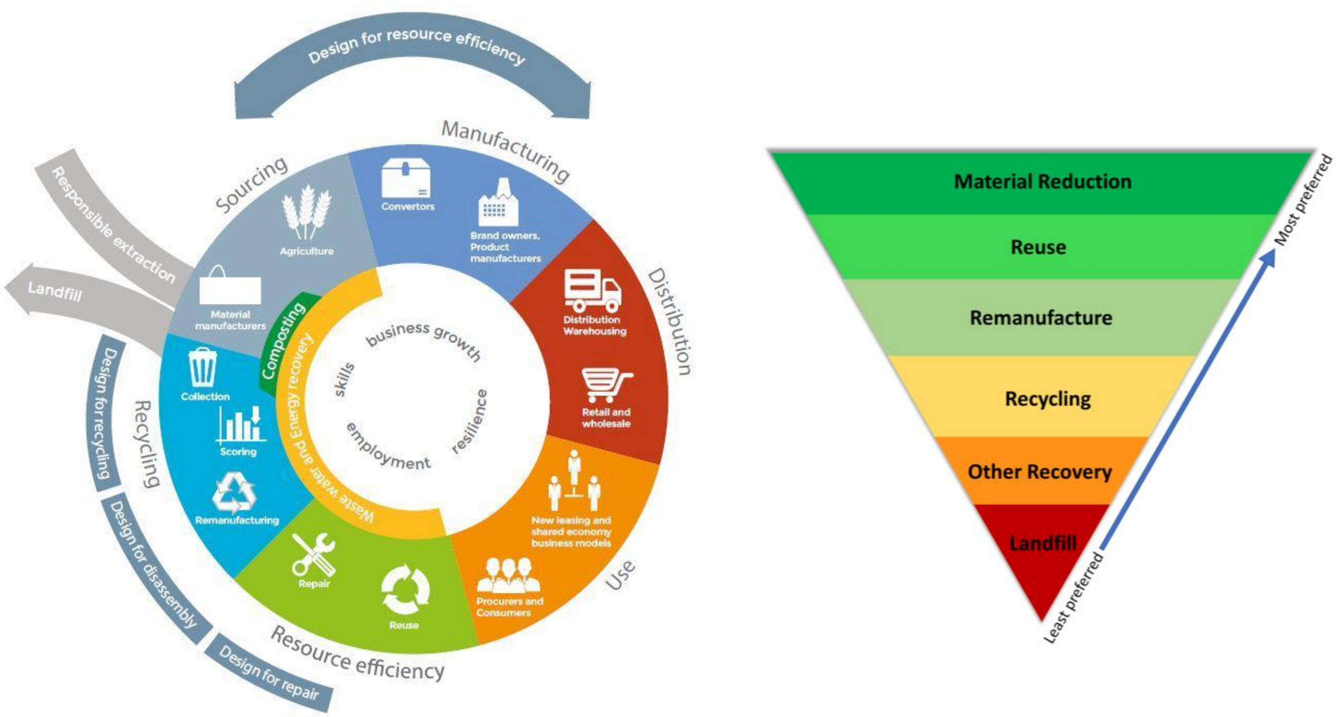
Landfill	the disposal of waste material by burying it
Municipal Solid Waste	Consists of household waste and other sources which are similar in nature that consists of everyday items that are discarded by the public and is collected by local authorities.
Mutagen	An agent such as radiation or a chemical substance that causes genetic mutation.
Needle Punched Carpet	Needle punched carpet entangles carpet fibres bonded with materials such as latex that creates a hard-wearing surface typically found in non-residential applications.
Off-gassing	Where something gives off a chemical, in the form of a gas.
Plasticisers	A substance to promote or produce plasticity and flexibility to help reduce brittleness.
Primary backing	The layer of the carpet that the face yarn is secured to.
Secondary backing	A secondary backing (or cushion) is attached to the primary backing with a body agent to provide further stability to the carpet.
Supply chain	The sequence of processes involved in the production and distribution of a commodity.
Surfactants	Used in the carpet industry as cleaning, dyeing, and rinsing agents, and are primarily used as a detergent in wool scouring where natural oils are removed from the wool and other textile fibres.
Tile	The production of carpet in modular tiles, predominantly seen in non-residential applications.
Toxic (substance)	A substance that can be poisonous or cause health effects.
Tufted Carpet	Tufted carpet has tufts of face yarn within the primary backing layer, locked into place using adhesives.
Upcycle	To reuse a product or material in such a way as to create a product of higher quality than the original.
Virgin material	Previously unused or raw material.
Woven Carpet	Woven carpet is a more traditionally produced carpet, created by interlacing pile yarn with backing yarns, locking them into place.

1 Introduction

The concept of the Circular Economy is entering the mainstream, notably through the EU's Circular Economy Package which aims to implement new Directives for various key waste streams, includes revised legislative proposals on waste, and an EU Action Plan for the Circular Economy [4]. Outside of government, many businesses are deriving substantial value from implementing Circular Economy (CE) principles into their business models, and the Ellen MacArthur Foundation's advocacy has helped to raise awareness of key issues and concepts[5]. While the concept of Circular Economy is interpreted differently in different regions, there is a growing agenda around implementation of resource efficiency, even in areas where the Circular Economy is perhaps not looked on as favourably as it is in Europe.

The Circular Economy is a model in which growth and prosperity are not intrinsically linked to natural resource consumption, as is the case for the current, consumption-based linear economy [6]. At its core, this means optimal use of resources by applying systems thinking, and using material & product lifecycles to make better design and manufacturing choices. While Circular Economy is often associated with improvements in recycling, it follows the Waste Hierarchy principle of: Reduction > Reuse > Remanufacture > Recycle > Recover for Energy > Landfill as shown in Figure 1[7].

Figure 1. The Circular Economy and waste hierarchy concept diagrams



From a broader perspective, Circular Economy requires actors at each stage of the value chain to participate, with producers taking greater responsibility for products placed on the market, consumer participation and engagement, and greater collaboration and involvement with the sectors which treat materials at the end-of-life. Often, the Circular Economy has to start with better product design, which is the responsibility of the producer, and must take into account the end-of-life and after-life of the product, the accessibility and recyclability of its components. Better design not only relates to the physical structure of products, but also to the materials and chemicals used to manufacture them – there is growing concern around toxic substances persisting in material loops as it is not always possible to remove them during the recycling process. Therefore, a shift towards elimination of hazardous substances where possible at the design stage is of key importance.

Carpets as a group have been identified as a product stream which is not being optimally treated at end-of-life[8], [9]. While there are some high-profile, manufacturer-operated carpet takeback programmes in place in Europe, the return volumes are small in comparison to the total carpet waste arising each year; additionally, many of the products returned are not easy to recycle. Of the waste carpet arising in the EU each year, the vast majority is likely to be landfilled, a large proportion incinerated, and only a few percent recycled.

There are several barriers to recycling carpets. The focus of this report is on toxic substances used during the manufacture of carpet and carpet materials as well as post-treatment processes which may lead to human and/or environmental exposure across a carpets life cycle. This is an area which is important on several levels: firstly, a variety of substances present a health hazard to actors across the product's lifecycle — those involved in manufacturing, installers, end-users (particularly more vulnerable groups such as children), cleaners, those removing the carpets at end-of-life, and those involved in management and processing of waste carpet. Secondly, recycled material containing these substances can then be used again in other products, therefore exposing more people to their toxic effects. Lastly, these pose a substantial environmental risk, through migration of substances into the environment during use or end-of-life processing, from leaching when carpet is disposed of in landfill sites, and from hazardous thermal decomposition products generated during incineration. Additionally, the presence of some hazardous substances can hinder reprocessing of plastics during mechanical recycling.

This study identifies major hazardous substances which are used in carpet manufacturing in the EU, or in carpets imported into the EU, which are of key concern from an environmental and health perspective across their lifecycle, and which potentially need to be carefully controlled to facilitate safe recycling of end-of-life carpets.

1.1 Carpet Types

One of the major challenges in carpet recycling arises from the variety of different carpet types and materials. These are outlined below.

1.1.1 Carpet Form

Firstly, carpet may be classified in terms of form: Broadloom and Tile.

Broadloom: production of carpet on a wide loom, producing rolls. Broadloom carpets may be made using several different techniques and materials, and are used widely across residential, non-residential, and other applications (e.g. transport). Broadloom carpets are often installed with a secondary backing, typically consisting of materials such as polyurethane (PU), polyvinyl chloride (PVC), or other latex-like or foam materials such as styrene butadiene rubber (SBR). From a materials efficiency perspective, there are several drawbacks with broadloom: firstly, there is often significant wastage during installation (although offcuts are often taken back by retailers or manufacturers); secondly, it is difficult to repair the carpets during the use phase (certainly compared to tiles); thirdly, reuse can be impractical[10].

Tile: the tile carpet market has grown substantially in the past 20 years. Tile carpet is modular, with a standard size of 50 x 50 cm, and is usually installed using adhesives which do not hinder uplift (sometimes referred to as tackifiers), facilitating redeployment, repair, and reuse. As with broadloom, the face yarn of tile carpet can be produced using several different techniques and materials. Tile carpet installation typically produces less waste than broadloom, and tiles can be replaced easily if worn out[11]. While these carpets are predominantly used in non-residential applications, there is a growing fledgling market for residential tile. Tile carpets typically come with a heavy backing, typically made from bitumen and PVC, making them significantly heavier than broadloom carpet per m^2.

1.1.2 Face Yarn Production

There are several techniques used to build the face yarn of a carpet – notably, these techniques may be applied to both tile and broadloom. The method used to produce face yarn can have a strong influence on the recyclability of the carpet, as some carpet types are harder to disassemble than others. The majority of face yarn is composed of synthetic fibres, with polyamide (PA, polyamide) being the most prevalent, and polypropylene (PP) and polyester (PET)[1] also used in large quantities. Natural materials, especially wool, are enjoying a resurgence in Europe, and we estimate that these now command around 10 % of the market, with greater popularity in regions such as the UK[12]. Blended fibres are also used widely, which can pose issues for separation and in many cases where the materials cannot be separated, totally precludes recycling.

Needle-punching entangles carpet fibres, bonding them with materials such as latex. This creates a hard-wearing surface, making needle-punched carpets very popular in non-residential applications. These carpets (broadloom type) are typically thinner than other types. Single-fibre needle-punched carpets can be recycled – for example, Reeds Carpets in the UK have a closed loop recycling programme for their polypropylene carpets [13] – whereas blended ones will be typically sent for energy recovery due to difficulty in sorting the polymers. However, only small quantities of needle punched carpets are likely to be recycled. Needle-punched carpets are popular for hard-wearing applications, as well as event/exhibition carpets.

Tufted carpets have tufts of face yarn within a primary backing layer (such as polypropylene), locked into place using adhesives such as styrene butadiene rubber (SBR) latex. A secondary backing layer (polypropylene, or woven fibres such as jute) is used for stability. Tufted carpets are more easily material-separated than others, with equipment for shaving off the face pile used by many recyclers. The resulting fibre can be recycled into new fibre in some cases (particularly polyamide-6), or downcycled to produce felts, equestrian riding surfaces, insulation, or horticultural bedding. Tufted carpets make up the vast majority of carpets sold in the EU, around 70–80 % [14].

Woven carpets use more traditional processes, with the pile yarn locked into place by backing yarns, making them hard-wearing. Due to the interweaving, the fibres are hard to pull apart; however, it is possible to process woven carpets to make felt, even where different fibre mixes are used. However, at present, the majority of these carpets will be used in energy recovery. Woven carpets are generally quite expensive and make up a relatively small part of the market, ~6 % in the UK (considered an upper limit for the EU)[15].

[1] Polyester is the common name for polyethylene terephthalate textile materials (PET), which also a key material used in packaging. Polyester is also commonly abbreviated to PE or PES.

1.1.3 Supporting Layers and Backing

Supporting layers and backing materials typically make up the biggest proportion of a carpet's weight, especially in the case of tile. The primary backing layer supports the face yarn; this can be a non-woven material (e.g. polyester), or a natural material (e.g. cotton)[16].

Interlayers can be used to provide further stability or cushion (e.g. glass fibre layers), as well as to bind the primary and secondary backings together (e.g. synthetic latex such as styrene butadiene rubber).

Secondary backings provide dimensional stability to carpets: a wide range of materials can be used here, such as jute, polyester, bitumen, PVC, or polyurethane, depending on the carpet form or application. These materials often use fillers, such as calcium carbonate, while in the US, fly ash has been used as it can be labelled as recycled content[17]. It remains unclear as to whether fly ash can be found in carpet manufactured in or imported into the EU.

Due to the complexity of the structure of backing layers and extensive use of latex adhesives, these components tend to be hard to recycle and are likely to be landfilled or incinerated. Improvements in backing layer separation and material selection should be a design priority to improve carpet circularity and some manufacturers have made significant strides in this area, with the Niaga-DSM partnership making this a key part of their mission.

1.2 The EU's Carpet Market[2]

The EU is the second biggest market in the world for carpet after the US, as well as being one of the largest producers: Belgium, the Netherlands, and the United Kingdom are the EU's leading manufacturing countries. Overall, we estimate that 65% of EU demand for carpets is fulfilled by EU-based manufacturing, which is high compared to other textile products. Additionally, 17 % of EU production is exported, with the US being the most popular destination, and the European Free Trade Area (EFTA) countries, Russia, the UAE, Australia, and Japan receiving significant volumes[18]. The United States imported carpet valued at $600 million from Europe in 2016, mainly from Turkey (valued at $267M) and Belgium ($95M)[19].

The demand for carpets in the EU amounts to almost 1.8 million tonnes (Mt) per year, while around 1.6 Mt arises[3] per year as waste[8], [9], suggesting that there is a slight growth in the overall carpet stock in the EU. It should be noted that there is also a significant market for carpets in non-EU countries in Europe, notably in areas where there are high levels of construction activity, such as Russia. Broadloom continues to be the most popular carpet form, although there are indications that the carpet tile market will continue to gain market share, particularly for commercial applications[20].

[2] We have produced estimates for carpet sales volume and waste arising per year from publicly available data. Further information on the research methodology is given in the Appendices. Note that these figures are used to provide an idea of the scale of the carpets issue, and require further study to corroborate.
[3] This figure is an old estimate which requires further study. For reference, Carpet Recycling UK estimate that around 400 kt of carpet arises as waste each year in the UK alone, amounting to ~6kg / capita[69].

Table 1. 2016 estimates for carpet manufacture and demand in the EU[4]

EU Demand (m^2)	EU Production (m^2)	Imported into EU (m^2)	Exported out of EU (m^2)
698,000,000	548,000,000	245,000,000	95,000,000

Application	%
Residential	55 %
Non-Residential	39 %
Other (Transport)	6 %
Carpet Type	% by area
Broadloom	87 %
Tile	13 %
Weight of Carpet Sold Per Annum	Total Waste Carpet Arisings Per Annum
1.77 Mt	1.6 Mt

A 2017 report by Changing Markets and Zero Waste France also shed light on the use of carpet in the events sector in France, and which is broadly applicable across the EU: exhibition events and trades shows typically install new carpets for the length of the event (usually a few days), after which they are uplifted and discarded[8]. This report estimated that around 6,000,000 m^2 of carpet is employed per year in France, while Reeds Carpets, a UK-based supplier, estimates that the UK events industry uses 12,000,000 m^2 per year[21]. Event carpet is typically needle-punched broadloom and relatively lightweight[22]; however, this still amounts to significant tonnages of waste (we estimate this to be around 12 kt for the UK and France combined, and potentially over 30 kt for the EU as a whole if this demand is extrapolated over the region), particularly given the short lifetime of the carpet.

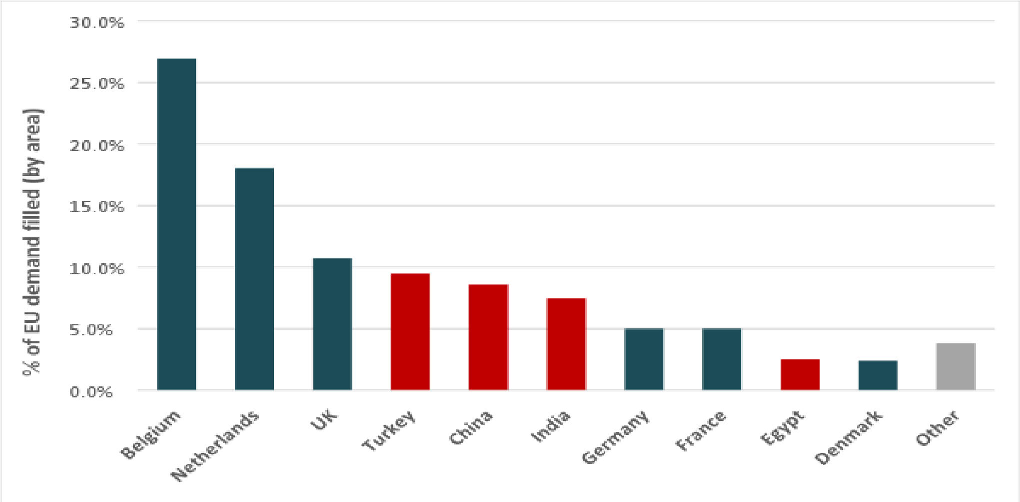
For installed carpet, typical lifetimes are around 7–15 years depending on durability, foot traffic, and style tastes, and while there is a sapling tile reuse market, most carpet only has one life (broadloom carpet is generally extremely hard to reuse)[10]. As such, yearly waste arisings are expected to reflect the carpet sales market ~10 years prior, which can be challenging for a recycling market which requires stable incoming volumes to remain economically viable.

1.3 Where are the EU's Carpets Made?

We estimate that around 65 % of the EU's carpet demand is fulfilled by manufacturers based in the EU, and relocation of industry has been less pronounced than for some other sectors. Turkey is a major global centre for textile manufacturing, and is the leading carpet exporter to the EU (with at least one major European manufacturer having manufacturing facilities in the region), followed by China and India. Turkey and India predominantly export woven carpets, whereas China mainly produces tufted needle-punched carpets[18].

[4] Determined from market research and trade data. Further information on the research methodology is given in the Appendices

Figure 2. Top ten countries producing carpet for use in the EU, estimated using the methodology and sources outlined in the Appendices.



1.4 Key Manufacturers

Key manufacturers of carpets consumed within the EU are summarised in Table 2.

Table 2. Key manufacturers of carpets consumed in the EU (from publicly available data)

Company	Company Base	Manufacturing Locations	Estimated European Revenue[5]	Notes
Tarkett	France	Canada, US, China, Ukraine, Serbia	€2,715m[6] [23], [24]	Also owns Tandus
Balta Group	Belgium	Belgium, US, Turkey	€430m [25]	
Interface	US	Australia, China, Netherlands, Thailand, UK, US	€198m [26]	
Milliken	US	US, UK, China, Australia	N/A	
Beaulieu International Group	Belgium	Belgium, Spain	N/A	Also has polymer and yarn manufacturing facilities
Desso	Netherlands	Netherlands, Belgium	€202m [9], [27]	Now owned by Tarkett
Associated Weavers	Belgium	Belgium, Czech Rep., France, UK	€175m [28]	Part of Belgotex International Group[7]

[5] Usually includes entire European region, not just the EU

[6] For Europe, Middle East and Africa

[7] Includes Nyobe (BE), PA yarn producer; Associated Weavers Europe (BE); Balsan (FR), carpet manufacturer; and other operations in South Africa, Brazil, and Australia.

Company	Company Base	Manufacturing Locations	Estimated European Revenue[5]	Notes
Forbo	Netherlands	France, Netherlands, Russia, Switzerland, UK	€155m [29]	
Brintons	UK	UK, India, Poland, Portugal	N/A	Owns Agnella, a major Polish carpet producer
Egetæpper	Denmark	Denmark	€135m [30]	

These manufacturers supply to households and businesses through a wide range of retailers and distributors, from large national companies to smaller local providers.

1.5 Barriers to Recycling Carpets

While this study focuses on toxic substances, this is just one aspect which presents a barrier to recycling carpet.

Design: Carpets are rarely designed with recycling in mind: there are several different types of carpet construction (tufted, needle punched, woven), and a broad array of materials used, both in the face yarn, and in backing material. Multi-layered materials can also be problematic, and blended yarns are usually downcycled through shredding, rather than being used to create fresh yarn. Additionally, certain materials such as SBR latex and bitumen cannot be recycled, and for many materials there is no commercial capacity for recycling at this point. Different types of carpet require different strategies for disassembly, and in several instances, the combination of construction type and materials make recycling technologically and/or economically infeasible. While this is being addressed, particularly in the tile market, these practices have not yet reached the mainstream; however, projects such as Niaga's monomaterial carpet are promising [31].

Collection: Carpet collection presents a number of challenges. Firstly, the use of adhesives in common for installation which can make carpets difficult to remove, and they are frequently damaged during uplift which can be problematic from a recycling perspective. Secondly, while significant amounts of carpet arise as waste each year, individual lots (i.e. those removed from a single premises) are typically low volume, although this problem is less pronounced in the B2B sphere. While there is infrastructure in place for the collection of carpets, particularly in the enterprise sphere, there are differing levels of awareness (both on the part of retailers and consumers), and household carpet is often collected as part of the general bulky waste stream rather than through dedicated collection routes. The diversity in carpet materials and construction can pose a problem if recyclers do not receive adequate volumes of a carpet type. The growing popularity of tile carpet addresses some of these issues – generally, these are fitted using releasable adhesives which aid de-installation, [32]and there is a growing tile reuse sector, particularly where premises undergo refit before carpets reach end-of-life[33]. Collection issues are highlighted by the events sector which accounts for an estimated 5 % of Northern Europe's carpet demand each year: while there is a significant opportunity for reuse and recycling, this is rare, and most of the carpets are single use and disposed of immediately after.

Contamination: material contamination and soiling is a major issue in recycling, and is a common problem in waste management of packaging materials. A combination of the use of adhesives during installation and their use profile, carpets are prone to heavy contamination and ideally require deep cleaning prior to end-of-life processing[10]; this is exacerbated when carpets are not removed early on in the renovation or demolition process. Additionally, carpet waste is often bulked at collection sites, and can be stored in ways which may increase contamination (e.g. in a ground pile, left outside). Heavy contamination makes it economically unfeasible to recycle carpet due to the additional stages required to reclaim the material, and therefore carpets received in this condition will likely be sent for incineration.

Toxic Substances: a broad range of chemical substances, many of which are toxic, are used in the manufacturing process of carpets. They can remain in the recyclate and contaminate the products in which they are subsequently used, and they pose a general hazard for people across its lifecycle. For example, many of the materials used in carpet need to be cut, ground, and/or melted during manufacture or during end-of-life – generating dust and vapour - potentially leaving workers exposed. Consumers are exposed to toxics in carpet through dermal contact as well as through the migration of chemicals into air and household dust which can be inhaled or ingested. Additionally, in some cases the presence of toxic substances can hinder recycling processes (particularly in mechanical recycling) as they can impact the quality of the recycled end material and increase the overall process costs. Toxic substances may also aggregate in recycled material, posing greater risk to those in exposed to these materials. These toxic substances are the principal subject of this report.

2 Hazardous Substances , the EU Legislative framework, and the Circular Economy

With the EU's push towards a Circular Economy, there is growing concern among policymakers that toxic substances will be recycled unknowingly and remain within circulation, and this agenda has been adopted by NGOs such as the European Environmental Bureau (EEB)[34], Health and Environment Alliance (HEAL), IPEN, BEUC[35] [28], and the Centre for International Environmental Law, driven, for instance, by reports of persistent organic pollutants ending up in consumer goods such as children's toys[36]. Without adequate screening techniques, it can be hard to identify sources of chemical contamination, and this issue may lead to much more stringent standards concerning recycling inputs. As such, the current standards of carpet manufacturing present a major obstacle to recycling, and emphasis the need to implement better practice, from product design through to manufacture, in the short term. Unfortunately, owing to the typical 7–15 year lifespan of carpets, waste processors will still have to manage the current installed stock of carpets, and the recycling industries may require additional support in order to effectively process this waste stream in an appropriate way until better designed carpet starts to reach their end of life stage.

2.1 EU Legislation: Chemicals, Carpet Manufacture, and End of Life

There are separate areas of EU legislation which affect carpets and the chemicals used in them at each stage of the product's lifecycle. On the global stage, the EU's upstream regulation of chemical use has been pioneering and ambitious in scope; moreover, its regulation of certain product groupings, e.g. the Restriction of Hazardous Substances (RoHS) in Electronics and Electrical Equipment has driven changes in manufacturing practices worldwide, notably in the widespread adoption of Pb-free solder and the shift away from the use of several halogenated flame retardants. For end-of-life material, the Waste Framework Directive has helped to drive collection rates for various product streams, and the adoption of landfill taxes by member states has played an important role in reducing dependence on landfill.

With the EU aiming to transition to a Circular Economy, to consider material lifecycles, and to reframe waste as a resource, there is a need for harmonisation and complementarity between these different pieces of legislation. Individually, these different pieces of legislation have made significant positive contributions to their respective areas; however, the European Environmental Bureau, BEUC, CHEM Trust, and Zero Waste Europe (among others) have indicated[34], [35], [37], [38], there are currently some disconnects between the different pieces of legislation which apply to different phases of product lifecycles, which may lead to exposure to hazardous substances due to unwitting recycling of material contaminated with hazardous substances, which persist in the material loop and environment for a long period of time.

2.2 Chemical Regulation: Manufacture & Upstream Use

In the EU, chemicals are regulated through three complementary pieces of legislation: CLP, REACH, and POPs.

Classification, Labelling, and Packaging: CLP Regulation

The CLP regulations stipulate that all chemicals placed on the market in the EU are to be classified based on the UN Global Harmonised System (GHS) of classification and labelling[39]. Depending on the substance, this can confer additional obligations around notification of the European Chemicals Agency (ECHA), labelling packaging with hazard information etc., and packaging hazardous substances in a suitable way to protect the end-user. Notably, CLP applies both to substances in virgin material and in recovered material. It also extends to polymers (plastics).

Registration, Evaluation, Authorisation and Restriction of Chemicals: REACH

REACH is a legislative regulation required to produce and sell products containing chemicals in the European Union (EU). The main objectives of REACH are to protect human and environmental health by understanding and managing the risks of chemicals[40].

Registration: Substances manufactured or imported into the EU in quantities >1 ton/year must be registered (in the form of a registration dossier) with ECHA. Registration obligations apply only to substances and currently exclude polymers. Although some other minor exemptions apply, virtually all substances, hazardous and non-hazardous, require registration. Companies are responsible for collecting information on the properties and uses of the substance they manufacture or import when manufactured or imported in quantities >1 tonne/year [41]. They do this through the registration dossier. The registration dossier requires a minimum level information regarding hazards, exposures, risks, and control measures[42].

Evaluation: Substance Evaluation is an integral part of the REACH implementation[43]. Substances are evaluated to determine whether their use poses a risk to human or environmental health. To clarify the risks, the registrants may be asked for more information on the substance. Substance evaluation is carried out by nominated Member States, while ECHA is responsible for dossier evaluation. The substances to be evaluated annually are listed in the **Community Rolling Action Plan (CoRAP)** by Member States[44], [45]. The aim is to identify hazards and associated risks – not manage risks - that were not identified as part of the original registration dossier and to make recommendations on next steps. Next steps may conclude that no action is necessary or the substance may be assigned to have Risk Management Options Analysis (RMOA) carried out. **The Public Activities Coordination Tool (PACT)** allows the public to track progress and have access to possible options being considered**.**

Authorisation: The aim is risk management and ensures **Substance of Very High Concern (SVHCs)** are progressively replaced[46] where risks cannot be effectively managed. The first step in identifying a SVHC is that a Member State must submit a proposal to identify a substance as a SVHC to the **Registry of Intentions (ROI)**. Once the proposal is published in the ROI, anyone may comment to provide information on the substance within 45-days. If no comments are received, the substance is automatically added to the Candidate List. If comments are received then the comments are referred to the Member State Committee (MSC) to agree on whether the substance should be identified as a SVHC and consequently added to the **Candidate List**. Substances are added to the Candidate List and prioritised for eventual inclusion on the **Authorisation List** (Annex XIV) where they will eventually be banned from commerce *unless an authorized use is granted*.

SVHCs include:

1. Carcinogens, mutagens, and reproductive toxicants (CMR) categorized as IA and IB under CLP
2. Substances identified as persistent, bioaccumulative and toxic (PBT) or very persistent very bioaccumulative (vPvB) according to REACH Annex XIII
3. Substance on a case by case basis that cause equivalent level of concern (e.g. some endocrine disruptors)

Restriction: The aim is to control known risks which cannot be managed by other risk reduction measures[47]. A Member State, or ECHA, at the request of the European Commission, can start the restriction procedure when they are concerned that a certain substance poses an unacceptable risk to human health or the environment[48] within a particular use of set of uses. Restrictions are normally used to restrict or ban the manufacture and placing on the market (including imports) of substances for certain uses. A restriction may apply to any substance either on its own, in a mixture, or in an article. Authorisation is the process of identifying substances of high concern for the eventual ban in commerce. This Authorisation process could take years and a restriction may be necessary for certain uses of a substance that are on the Authorisation List because unreasonable risk has been identified – example**: CMRs in textiles**. There is currently a proposal for a Restriction of Carcinogenic, Mutagenic, and Reproductive toxic substances (CMR) for textiles[49] . Some CMRs in the proposed restriction may be on the Authorisation list, but not yet banned from commerce. The restriction in textiles would make them banned from that particular use before their complete ban from commerce. Once the restriction has been adopted, industry must comply. That means all including manufacturers, importers, distributors, downstream users and retailers. The Member States are responsible for enforcing the restriction.

Annex III Inventory

Annex III inventory of substances is a list of substances likely to meet Annex III hazard criteria to the REACH regulation (CMR, PBT/vPvB, or other hazardous criteria) and/or have disperse use. The presence of a substance on the inventory is a not a tool for classification but rather shows an indication for concern. It does mean, however, that publicly available databases with experimental data and chemical modelling were used in drawing conclusions that these chemicals are of concern and that evidence should be gathered in making an affirmative classification.

Community Rolling Action Plan (CoRAP)

CoRAP indicated substances that must undergo evaluation by the member states within three years of their inclusion to the list. ECHA and the Member States develop risk-based criteria on which substances are selected for the CoRAP. Member states contribute to the CoRAP process by identifying priority chemicals for possible inclusion.

The evaluation under CoRAP aims to clarify the initial concerns of the substance and identify whether the potential exists that the substance poses a risk to human or environmental health. Many substances are added to the CoRAP list because of concerns they might be PBT, CMR, endocrine disruptor or substance of equivalent concern. The addition of a substance to CoRAP only indicates a possible risk as the substances identified have not been fully evaluated [50]. The process often results in requests for further data.

The Public Activities Coordination Tool (PACT)

The Public Activities Coordination Tool (PACT) is an informal communication tool and as no legal standing under

REACH. The purpose is to give advance notice of substance that are on a particular authority's radar for regulatory risk management[51].

PACT lists the substances for which an informal hazard assessment is under development in order to determine if the substance is a PBT, vPvB or endocrine disruptor. If the substance appears to be a concern, it typically goes through risk management option analysis (RMOA).

Inclusion in the PACT means that a Member State or ECHA is examining the substance, it does not mean that a substance has the suspected properties or that there is need for regulatory risk management actions. The purpose of the hazard assessment is to explore a potential PBT/vPvB or endocrine disruptor concern. PACT gives stakeholders additional time to prepare for changes should a substance become part of a formal risk management process such as being identified as a SVHC or restricted.

Persistent Organic Pollutants: POPs Regulation

POPs are substances which are known to persist in the environment and which have potential for bioaccumulation; at present there are 26 substances which are covered by the POP regulation. The regulations cover the lifecycle of these substances, and restrict their production, placing on market, and use, as well as managing their end-of-life and mitigating accidental release[52]. Use of Annex I substances is prohibited, and there are regulations to limit recycling of materials containing these substances.

Biocidal Product Regulation: BPR

The Biocidal Products Regulation (BPR, Regulation (EU) 528/2012) concerns the placing on the market and use of biocidal products, which are used to protect humans, animals, materials or articles against harmful organisms like pests or bacteria, by the action of the active substances contained in the biocidal product[53], [54]. This regulation aims to improve the functioning of the biocidal products market in the EU, while ensuring a high level of protection for humans and the environment.

Biocidal products require an Authorisation before they can be placed on the market, and the active substances contained in the biocidal product must be approved for their intended use (some exemptions may apply such as substances previously approved under the old BPR legislation which are currently under review)[55].

An authorized use as a biocide does not mean the biocide is non-hazardous, it just means the biocide is authorized for a particular product type: there are 22 biocidal product types, grouped into 4 main areas[56]. The BPR sets rules for articles such as carpets treated with, or intentionally incorporating, biocidal products[55].

2.3 Product Legislation

While there are a number of product-group specific directives which aim to ensure product safety (e.g. through restriction of chemical use, fire safety etc.) and to drive sustainability (eco-design, promoting reuse/recycling), there is currently minimal legislation directed specifically towards carpet, and none which address the full scope of requirements that are necessary to support less toxic recyclable carpets at scale. The following Directives identify legislation that may be applicable to carpets and where thought should be given to how these existing pieces of legislation may complement a Directive specific to carpets.

General Product Safety Directive (GPSD)

The EU General Product Safety Directive (GPSD) is implemented by Member States to ensure that articles on the market do not harm humans health or safety. From a general consumer safety perspective, the General Product Safety Directive may be applicable to carpets. GPSD stipulates that only safe products are placed on the EU market, either through adherence to EU product-specific legislation, or through national standards (based on EU ones)[57]. This can be used to limit hazardous chemical use in products, and may be used to recall products found to be potentially hazardous to consumers.

Toy Safety Directive (TSD) 2009/48/EC[58], [59]
The general provisions of the EU's Toy Safety Directive define what constitutes as a toy, outlines technical documentation requirements, establishes production control and more. Chemical requirements of this directive include restrictions on toxic chemicals as well as the use of CMR substances and includes the following categories under CLP and corresponding concentration limits.

Table 3. Toy Safety Directive, categories and concentration limits

Hazard Category	CLP Classification	Concentration*
Carcinogenicity & Mutagenicity	Cat 1A & 1B	0.1
Carcinogenicity & Mutagenicity	Cat 2	0.1
Toxic for reproduction	Cat 1A & 1B	0.3%
Toxic for reproduction	Cat 2	3%

*These concentration limits apply if no specific concentration limit exists for a particular substance[60]

As can be seen, this regulation goes beyond other regulatory frameworks, such as REACH, to remove known CMRs from children's toys. Carpet specific legislation that addresses chemicals of concern[8], similar to that of toys, should be justifiably created, given the amount of time infants and small children spend on the floor.

Construction Product Regulation (CPR) (Regulation 305/2011) & Harmonised Standard EN 14041
The CPR is the regulation that establishes the requirements for placement of construction products on the market. EN 14041 is this standard which specifies the health, safety, and energy saving requirements for resilient, textile, and laminate floor coverings [61]under the CPR. Specifically, the standard governs carpet, PVC flooring, rubber flooring, textile flooring, and others. The main objective of the CPR is to establish a minimum set of health, safety, and performance requirements of construction products to allow free trade within the EU. Products meeting standard requirements should bear the CE marking (although not compulsory) and can trade freely within the EU.

There are multiple issues with this regulation and standard as their requirements seem to be governed by the avoidance of trade barriers and ensuring performance requirements - with less emphasis given to health and safety criteria such as the restriction and/or removal of chemicals of concern in carpet[49]. The work of CEN TC351 is scoped at addressing the presence of toxic substances in construction products, but most of its work is focused on emissions rather than content. It is also progressing at a very slow rate.

2.4 Waste Legislation

The Waste Framework Directive formalised the adoption of the Waste Hierarchy (Figure 1) in the EU, and governs authorisation of waste processing facilities, transport, handling of hazardous waste, and transportation. The WFD states that "*the classification of waste as hazardous waste should be based, inter alia, on the Community legislation on chemicals, in particular concerning the classification of preparations as hazardous, including concentration limit values used for that purpose.*"[7]. While this would suggest that hazardous substance classification is aligned with the chemicals legislation outlined above, in practice waste codes are commonly used to identify hazardous waste, as per the 2000/532/EC Decision: here, waste is classified by the waste collectors or

[8] For this study, "Chemicals of concern" are defined as category 1 and category 2 CMRs (Carcinogenic, Mutagenic and Reproductive substances), endocrine disruptors and other substances of equivalent concern.

processors according to its source (e.g. Construction & Demolition waste, Municipal waste, waste from the leather/fur/textile industries)[62], [63]. While SDSs should be available for waste from post-industrial sources (if requested by the waste collector), information on post-consumer waste will largely be non-existent, and these wastes will frequently be mixed together.

Under the European Waste Catalogue codes, carpets are likely to fall under 20 01 11 (Municipal Waste – Textiles), 20 03 07 (Bulky waste), or 20 03 01 (mixed municipal wastes), none of which are classified as hazardous. In any event, given the role of carpet in buildings, it is unlikely that operators would consider them to be hazardous, and screening municipal waste for hazardous substances is highly impractical. With the lack of information on the carpet origin or in-use treatment (*e.g.* antimicrobial or anti-stain), not only does the lack of identification potentially open up workers to exposure to the hazardous chemicals, but end-of-life treatment may not be appropriate, because it could lead to incomplete destruction of halogenated substances during incineration (treatment at insufficient temperatures), or persistence of flame retardants in post-consumer recycled plastic products. As a consequence, this increases the likelihood of hazardous chemicals in carpets persisting in recycled or downcycled materials.

2.5 Extended Producer Responsibility

Extended producer responsibility regulatory schemes are designed to pass the costs of collection and end-of-life treatment of products back to the producer with the objective of driving better product design, and the EU mandates that member states install such systems for key product streams such as electronics and batteries, and packaging EPR systems are common across the region; furthermore, individual member states can install similar systems for other products, e.g. clothing textiles in France[64], [65].

EPR is also used by the EU to limit use of hazardous materials where possible, as has been the case for electronic equipment and packaging. Recently, there have been some developments on hazardous substances in consumer products, with proposals for improved transmission of information around substances of concern to ECHA and a database available to waste operators and consumers; decontamination of hazardous waste where necessary; and modulation of EPR fees based on eco-design drivers associated with the Circular Economy Package. .

There are currently no extended producer responsibility schemes in place in the EU for carpets. However, there are growing concerns around carpet at a policy level, and there is a precedent, with the US state of California notably signing extended producer responsibility legislation into law in 2012, and has just been updated to require a 24 % recycling rate by 2020[66]; at the federal US level, there is a voluntary stewardship programme run by industry, CARE, which has received criticism for not meeting its recycling goals and making recyclers sign that they will not support EPR legislation anywhere[17], [67]. With California implementing the world's first carpet EPR system, it is likely that the EU will see this as area to review and consider for EPR.

In the EU Member States, bulky wastes such as carpet and mattresses are a growing problem for local governments. In the UK, an earlier WRAP study found that around 5 % of the household bulky waste stream consisted of carpet, with ~22 kt collected by councils at the kerbside, and 82 kt taken to municipal recycling centres. Bulky waste is typically very costly due to its high volume and, in the case of carpet, relatively low value of the material; as such, EPR systems are attractive to offset the logistics costs which are often extremely high[68], [69]. EPR systems may also be seen as an effective way of stimulating recycling, improving manufacturer stewardship of carpets, and improving their design. Some EPR systems in the EU already offer incentives for eco-design: for example, Eco-Emballages, the producer responsibility organisation for packaging in France, offer fee reductions for eco-design, specifically around material reduction, improved recyclability, and use of recycled content[70]. A similar system could be implemented for carpets (threshold for number of materials used, avoidance of 'difficult' materials such as SBR latex, bitumen or PVC, avoidance of chemicals of concern and non-recyclable materials)[66].

As well as covering end-of-life treatment, EPR also extends to manufacture: in the EU, the WEEE Directive for Electronic Waste is closely linked to the Restriction of Hazardous Substances (RoHS) legislation which restricts the use of 10 substances (Pb, Hg, Cd, Cr^{6+}, PBB, PBDE, and 4 substances of phthalate)[71]. Due to the importance of the EU to the global electronics market, there has been a largely global shift towards RoHS compliance, leading to the complete phasing out of Pb-based solder and key flame retardants by many manufacturers. Additionally, several countries have implemented their own RoHS-inspired legislation. Likewise, the EU's Packaging Directive also sets out heavy restrictions on Pb, Hg, Cd, and Cr^{6+}.

While EPR for textile products has been discussed by multiple EU member states, France is the only country which has implemented a mandatory system to this point, although this only covers clothing: this system mandates that producers pay between €0.00132 and €0.0528 per item depending on size to EcoTLC which administers the system[65]; there are also concessions for producers using recycled fibres (pre- and post-consumer), and small businesses (< €750,000 turnover per year) play a flat fee of €36. For comparison, the California Carpet Stewardship Plan passes the costs to consumers for finance, with a surcharge of \$0.25 per yd^2 (equivalent to ~€0.25 per m^{-2})[72].

There is growing support for EPR systems for carpets, mattresses, and furniture. For example, Zero Waste Europe have called for a producer tax on carpets and a corresponding refund based on the amount of carpet recycled[73]. Additionally, a recent paper by Wilts *et al.* on the Circular Economy potential of carpets recommended both inclusion of carpets with the scope of the EU's Ecodesign Directive, and to extending financial responsibility to producers to effect real change within the carpet industry[74], [75].

2.6 Policy Assessment

2.6.1 Positives

REACH is continually evolving
Innovation almost always progresses at a faster rate than policy. REACH has set a global standard for chemical regulation, and requires manufacturers to provide data on risk for chemicals placed on market; in contrast, many other systems have looser risk assessment requirements and often puts the burden on a central authority to demonstrate that a substance on market is hazardous in order to control it[76]. Owing to the extensive registration and testing requirements, REACH can evolve year-on-year to respond to new hazards, and is responsive to new data on hazards becoming available.

Product-specific legislation driving better manufacturing practice and protecting consumers
Legislation such as RoHS [71] for electronics has driven changes in material selection on a worldwide scale, providing better protection for those working in the waste industry. Additionally, the EU's Toys Directive has provided an additional layer of protection to vulnerable end-users by restricting chemicals usage and reducing risks through better design. Additionally, product-specific legislation allows for fast response (more so than REACH) in the case that substances are suspected of being hazardous. Additionally, regulations such as the proposed CMRs in textiles legislation, are starting to emerge around textiles in order to drive industry best practices consequently facilitating increased levels of worker, consumer and environmental protection.

The EU's waste legislation has drastically improved waste management in the member states
The Waste Framework Directive has formalised important concepts such as the Waste Hierarchy and the Polluter Pays Principle (passing environmental costs of waste back to the producers), and has helped to drive relatively high recycling and landfill diversion rates across the region. While the legislation requires reform to drive further growth of the Circular Economy and address some of the shortcomings of systems developed under the WFD, the extended producer responsibility frameworks have provided a blueprint for other countries to follow.

2.6.2 Gaps

REACH process is time consuming and potentially incomplete
Despite being arguably the most progressive chemical legislation to date and the candidate list having proven to be a major driver for innovation, the regulatory process to identifying and regulating SVHCs is slow moving, time consuming and in practice it can take years to restrict or ban these substances. On major hurdle in the process remains the overall poor quality of the hazard data in some registration dossiers, which are fundamental to the effective functioning of the regulation and a large majority of them are not being evaluated by ECHA and updated after the first submission. Finally, alternative chemical substitution has not been granted the resources it deserves so far, although recent developments are giving encouraging signals of the European Chemicals Agency (ECHA) commitment to progress on this aspect [77].

Chemicals legislation and secondary materials
While REACH requirements are often the same for both virgin and secondary materials, the loss of information between the upstream suppliers (manufacturers) and waste processors mean that hazardous substances may unwittingly persist at increased concentrations in recycled material. It could be technically feasible to screen secondary material for many of the hazardous chemicals that may be found in carpets. For example, Interface has a comprehensive array of chemical testing for incoming scrap. However, given the number of substances regulated under REACH, it is likely not economically feasible and nearly impossible to screen secondary material for all potential hazardous chemicals. Therefore, the elimination of toxic substances upstream remains the most effective solution. With the rise of asset tracking technology (e.g. QR codes, RFID tagging), it would be possible to implement mandatory tagging of certain products, connected to a database of bills of materials/substances to help end-users and waste processors effectively sort out contaminated material; however, this puts further burdens on the downstream actors. The European Commission announced it is launching a feasibility study, addressing representative sectors, on the use of different information systems, innovative tracing technologies and strategies which could enable relevant information to flow along article supply chains and reach recyclers.[78] This daunting task of monitoring hazardous substances in recycled materials suggests that it should be recommended to manufacturers that they phase out the use of hazardous chemicals in the design phase of new carpets.

Relaxation of concentration limits for recycled materials
There are some cases of concentration limits of hazardous substances for recovered materials being less stringent, e.g. the flame retardant pentaBDE, regulated under the POPs regulation, has a concentration limit of 0.001 % w/w for virgin material, but a limit of 0.1 % w/w in recycled material: this has ostensibly been set in order to protect recycling operations which would suffer from the reduced availability of feedstock, or from the extra costs associated with removing the substance during processing. While this protects recycling businesses (which operate under difficult market conditions), this poses a hazard to consumers and may lead to long-term persistence of legacy chemicals in in-use material stocks as well as undermining consumer confidence in recycled products. *"It will be much more difficult to identify and eliminate the concerned substances at later stages when re- cycled products will become waste," noted in an EC-commissioned report in 2011*[79].

Lack of product-specific legislation or standards for carpets
As mentioned, the EU's Toys Directive has provided an additional layer of protection to vulnerable end-users by restricting chemicals usage and reducing risks through safer design. As part of its main objective, the Toy Substance Directive has done a better job at setting stricter chemical limits and general toy safety requirements more efficiently than REACH or any other Directive applicable to toys. This suggests a Carpet Directive similar in approach is sensible.

While carpets are currently covered under the CPR product-specific legislation, the requirements of the regulation and standard are rather minimal – particularly in addressing chemicals of concern and better design towards a more circular economy – which should be a main objective of any product-specific regulation and/or standard governing carpets.

Disconnect in definitions of hazardous waste
The lack of harmonisation between the methods for classifying hazardous waste under the Chemicals and Waste legislation leads to waste containing hazardous substances (particularly post-consumer) being classified as non-hazardous at end-of-life, potentially leading to persistence of hazardous substances in secondary materials or released into the environment through disposal or incineration[34]. For example, flexible PVC waste containing toxic additives are often (mis)classified as 'non-hazardous' waste, although the resulting recovered product will be classified as a hazardous chemical mixture under the CLP regulation. From a practical standpoint, screening mixed post-consumer waste is not a viable solution, and elimination of substances from manufacture would be the most effective route to ensuring worker and consumer safety, and removing the threat of secondary material contamination (as there is no obligation to decontaminate waste before recovery).

2.6.3 Progression

2018 Circular Economy Package
The European Commission has published a communication entitled "*Analysis of the interface between chemicals, products and waste legislation and identification of policy options*" which aims to bridge these gaps across 4 areas[80]:

- Addressing information gap around substances of concern in waste streams
- Investigating potential frameworks for monitoring substances of concern in recycled materials
- Creating more concrete definitions around the delineation between waste and end-of-waste.
- Reviewing difficulties around waste classification and the impact on material recyclability

As reported in ChemicalWatch [81], because legacy substances – those chemicals for which restrictions were set in the past but may be present in products recycled from older materials containing them – are a barrier to recycling, the Commission plans to develop, by mid-2019, a specific decision-making methodology to support decisions on the recyclability of waste containing substances of concern. It aims to prepare guidelines to ensure the presence of hazardous substances in recovered materials is better addressed in the early stages of proposal drafts to manage their risks. And it is "considering enacting implementing legislation to allow an effective control of the use of the existing exemption from REACH registration for recovered substances". There are also growing calls for extension of Extended Producer Responsibility to other key product streams, such as textiles. [58]

CMR in textiles REACH Restriction Proposal
The EU is exploring restriction of CMR substances in consumer goods which pose a high risk of a exposure, which

would be implemented via Article 68(2) of REACH[82]. A public consultation was launched in late 2015: this proposed a two-stage phase-in of items, with the first stage limited to direct skin-contact interior textiles, and the second potentially covering floor coverings, carpets, upholstery, etc. The scope of a revision including carpet remains to be seen, and what sort of derogations would be included. Euratex has recommended that articles made from recycled materials should be excluded from the scope, or at least considered for derogation due to this potentially interfering with the EU's Circular Economy aims[83]. At present, the proposed restrictions would cover substances such as heavy metals, phthalates, PAHs, azo-dyes and others.

While carpet is considered to be a limited skin contact product, children are likely to be most at risk, particularly from topical treatments and dyes, and there is a strong argument for including carpets within this framework as later suggested in this report.

2.7 Manufacturer Trends

While the European carpet market is clearly in need of regulation to help to drive change, some manufacturers have taken positive steps towards making their products safer. Interface took the lead in eliminating PFASs from their carpets some years ago, and as of December 2017, Tarkett have announced that all of its Tandus Centiva branded products will be treated with fluorine-free soil protection products[84]. While there needs to be greater transparency around the substituted substances, given data gap around the toxicity of many classes of PFC (and historic mismanagement of this family of chemicals), this is a welcome step. Aquafil have also developed its Econyl® StayClean yarn, which claims a high level of stain resistance without using topical treatments[85].

With regards to transparency, some manufacturers are starting to disclose more information through voluntary standards such as Health Product Declarations (HPDs) and Environmental Product Declarations (EPDs). HPDs provide a standard format to enable product level disclosure of ingredients. EPDs communicate information about the life cycle environmental impacts of products. The use of HPDs/EPDs is a good step towards transparency, however, they don't always offer full transparency. For example, EPDs typically don't consider inputs under 1%, and therefore many high priority substances may not be reported. HPDs allow varying levels of disclosure. Additionally, EPDs and HPDs can be difficult to understand by the average consumer as they require certain knowledge on their methodology and terminology.

While some manufacturers have taken on their own initiatives to clean up carpets, many rely on certification to show their commitment to addressing environmental issues. Third party certifications such as GUT, Cradle to Cradle, Oeko-Tex, Nordic Swan, and Blue Angel resonate with consumers; therefore, it is important to ensure that the product standards within these programmes are up to date and maintain stringent standards around permitted chemical use.

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3 Current State of End of Life Treatment of Carpets

3.1 Current State in the EU

Of the 1.6 Mt of waste carpet produced in the EU each year, only 1–3 % is actually recycled[8], [9]; of this, the majority still reaches landfill, with incineration being the next popular route, either in energy recovery facilities or as an alternative fuel for cement kilns[86].

Table 4. 2016 estimates for carpet end-of-life treatment route, estimated using the methodology outlined in the Appendix III.

Weight of Carpet Sold Per Annum		Total Waste Carpet Arisings Per Annum
1.77 Mt		1.6 Mt
Recycled	**Energy Recovered (incinerated)**	**Landfilled**
< 3 %	37 %	60 %
0.048 Mt	0.592 Mt	0.96 Mt

Landfill: member states in the EU implement different controls over the use of landfill, with most EU member states (24 out of 28) charging a per-tonne landfill tax, and 11 others banning potentially combustible waste (such as Belgium, Germany, and the Netherlands). Landfill tax ranges from €3 per tonne (in Lithuania) to over €100 in Belgium, and there is a general trend towards increasing charges[87]. These have helped to drive the diversion of carpet from landfill, although the majority of carpet is still disposed of in this way. Recently, the EU has set landfill restriction targets for municipal solid waste, with an upper limit of 10 % by 2035 for all member states: effective management of end-of-life carpet will play a role in meeting this target[88]. Carpet is more or less a permanent material in landfill with an extremely slow degradation time; however, there is potential for the toxic substances within carpets to be leached out by precipitation. While there are standards for leachate and sludge management from landfill, some of the substances found in carpets can be difficult to manage and may be discharged after treatment. These recalcitrant toxic substances may be: 1) discharged into the environment after initial treatment; 2) sent to municipal waste water treatment facilities which are often times unable to manage these toxics and consequently discharged substances into water ways; 3) sent for incineration. Also, if carpets end up in poorly managed landfills, there is potential for substances to leach into the surrounding environment directly.

Energy Recovery & Incineration: energy recovery capacity has grown in the EU and plays a major role in the waste management strategies of member states. Carpet is disposed of either in incineration (energy from waste) plants to generate electricity and heat, or in cement kilns, and are used as a waste-derived fuel source due to its high calorific value. The EU Directives on Industrial Emissions (2010/75/EU) [89] and Medium Combustion Plants (2015/2193) [90] regulate incineration and emissions from incineration facilities, and require that flue gases reach a minimum of 850 °C for 2 minutes to enable decomposition of organic compounds; most countries have set specific limits for emissions of SO_2, NO_x, HCl, HF, Total Organic Carbon, CO, dust, heavy metals, and dioxins/furans. While fugitive emissions of toxic substances is possible, the majority of problematic toxic substances such as heavy metals and dioxins find themselves captured in the resulting fly ash – which contains toxic heavy metals and dioxins. In fact, the more toxic substances captured from emission end up created increasingly toxic fly ash which is then sent to landfill as hazardous waste or end up in concrete applications. It is clear that there needs to be a concerted effort by the manufacturing industry and recyclers to build recyclability into carpets at the design phase, as well as develop better recycling technologies in order to maximise material value and limit lifecycle CO_2 emissions. Due to the high incineration capacity in parts of Northern Europe [91] – which requires a constant supply of feedstock to maintain operation – Energy from Waste is likely to be a major competitor to carpet recycling.

Recycling: for recycling of broadloom carpet, whole carpets are either shredded (including the backing), or the face yarn separated from the backing using a splitting system. Due to the resulting mix of materials, whole carpet shredding is effectively downcycling of material, with it being used for applications such as insulation, equestrian surfaces, or felt [92]. Some designs of tile carpet are more easily separated into backing and face components (although this is not always the case, and bitumen can hinder the separation process as it melts easily)[10]; some manufacturers reuse backing from viable collected tiles. Separated face yarn can either be downcycled (as for whole-carpet shredding), or depending on the resulting mix of fibres, it can be recycled into new fibre, either chemically or through mechanical reprocessing. For example, Aquafil, who supply polyamide-6 fibres to several carpet manufacturers, processes material recovered from carpets into new yarn at their facility in Slovenia. While it is possible to separate some fibre blends, some (e.g. polyamide/PP) cannot be separated which can inhibit reprocessing[10].

3.1.1 Manufacturer Takeback Schemes

Some major manufacturers, usually those producing tile carpet, have set up takeback schemes for re-use and recycling, including Interface and Desso, while other businesses take back installation off-cuts (*e.g.* Forbo)[93]. While these schemes are relatively high profile, especially with Desso (now part of Tarkett) receiving EU funding through the Eco-Innovation and Life programmes to develop their processing capacity, takeback rates are thought to be quite low at present (< 5 % of sales volume)[9]. The challenge appears to not only lie in getting sufficient material back from the market, but the fact that post-consumer carpets which come back were historically not designed for recycling, therefore making it difficult to do so. Tarkett claims that their EcoBase backed carpet tiles are designed for disassembly and safe recycling with high quality outputs, demonstrating, Tarkett say, “that the future for carpets can look different, when products are designed accordingly”.

3.1.2 Design for End of Life and Recycling

There have been several developments, particularly in tile manufacturing, to improve the recyclability of carpets. The modular nature of tile carpet and the use of releasable adhesive which facilitate uplift and make it suitable for redeployment; additionally, several tile carpet manufacturers have engaged in research to facilitate separation of yarn from backing. Recently, the DSM-Niaga partnership has developed a technology for tufted broadloom and tile carpet which enables separation of yarn from backing (mono- or bi-material carpets), and has been incorporated into Mohawk’s Air.O range[94]. This uses single-material layers, a proprietary adhesive, and is free from latex-type materials which irreversibly bond layers together.

3.2 Recycling Plastics

The Circular Economy places a high value on “permanent” materials – those which can be infinitely recycled with minimal loss: these include materials such as metals and glass which have a long history of secondary production – for example, it is possible to upcycle a copper alloy back to 99.9 % purity copper metal. While this is a relatively energy intensive process, it is still more efficient than primary production for many scrap grades.

Plastic recycling is a young technology, given that widespread use of plastics has only come about in the last 50 years, and development of end-of-life strategies has lagged behind innovation in materials and processing. At present, the plastics recycling market is under significant pressure as it is struggling to compete with primary (virgin polymer) production due to a combination of low oil prices and cheap production supply from China and the United States (due to fracking, ethylene capacity is projected to more than double this decade [95]. Ethylene is a building block for the vast majority of plastics, including polyethylene and PVC). Additionally, the demand for recycled plastics can be extremely variable, especially as many businesses perceive that secondary plastics should be much cheaper than virgin material, as well as there being concerns over material performance. At present, plastic recycling requires R&D investment, as well as stable demand from businesses to remain economically viable. Plastics are currently receiving significant attention from a sustainability perspective with the EU Circular Economy Package (including a plastics strategy which is due to be published in early 2018), the Ellen MacArthur Foundation's New Plastics Economy paper[96], and the marine plastics issue putting the spotlight on the material (including a UN Resolution to address the issue) [97], [98] and this is starting to drive greater commitment from businesses in the use of recycled plastic content.

From a process perspective, economic viability of plastics recycling depends on several factors: stable input volumes, simplicity of processing, effective sorting, acceptable contamination levels, and strong demand. Design for recycling plays a substantial role here: facile layer separation, limited material selection (and avoidance of blended materials), and a degree of industry standardisation would all reduce the costs associated with recycling, as well as allow for inclusion of key processing stages (e.g. additional decontamination/cleaning stages where required). Another big challenge is plastic colouring, which is exacerbated by the sheer range of finishes and dyes used (as well as uniformity, particularly in the case of post-dyeing)[99].

Table 5. Recycling Definitions

ASTM D5003 definitions	ISO 15270 definitions	Other terms
Primary recycling	Mechanical recycling	Closed-loop recycling/Feedstock
Secondary recycling	Mechanical recycling	Downcycling
Tertiary recycling	Chemical recycling	Depolymerisation/chemical recycling

Generally, plastics used in carpets may be recycled in two ways: mechanically and through depolymerisation[100]. Mechanical recycling is currently more common and is typically more economically viable than depolymerisation, and it is a less energetically intensive process. Mechanical recycling processes can be used to create secondary feedstock for plastics production (where recycled content pellets are mixed with virgin material, followed by extrusion or other processes), or to downcycle carpet material for other applications. Recycled plastic content is usually differentiated between post-industrial (material waste generated during production) and post-consumer. However, depolymerisation can be used to create virgin plastics from recycled material, whereas repeated cycles of mechanical recovery will degrade the material quality. Therefore, ideally plastic products would be marked with their material information and recycled content, helping waste processors to assess whether an item would be best suited to mechanical recycling or depolymerisation.[9]

Mechanical Recycling – feedstock: after collection, sorting into single plastic streams, and selection of material (i.e. removal of contaminants), the plastic is shredded and cleaned, usually by a hot wash process. This produces plastic granules or flakes, which can then be used for extrusion moulding to produce recycled content fibre (or other methods to produce other plastic products). This method is used to create PET fibre from post-consumer plastic bottles, which are typically a source of high-quality PET. While this is an effective way of cycling materials, mechanical processing does degrade the material at a chain level, and there is a limit to the number of times that plastic can be recycled in this way (although this does not preclude depolymerisation). Additionally, coloured and dyed plastics present a processing challenge, and the process does not guarantee removal of contaminants from the material, potentially allowing toxic substances to persist in material loops.

[9] Typically, the physical properties of plastics deteriorate with increasing recycled content. From a mechanical recycling standpoint, virgin plastic is the most desirable feedstock. The higher the recycled content, the lower quality the recyclate is, and past a certain level of recycled content, the optimal processing route would be depolymerisation.

Mechanical Recycling – downcycling: most commonly, carpets are downcycled through bulk shredding. While some recyclers are equipped with machinery to separate the face from backing, some simply shred the entire carpet, with unusable material sent for energy recovery. The resulting material mix can be used in various applications, including equestrian surfaces (almost 20 % of Carpet Recycling UK's collected carpet)[10], [12], felts, fibre for needle-punched carpets, insulation, and concrete filler[101]. These applications do not always include material washing, and therefore contamination can persist in these materials through their continued use. The use of shredded materials, generating microfibers with potentially toxic substances attached, can spread the problem significantly, especially when spreading in the open environment for instance on equestrian surfaces. Due to the mixed nature of the resulting fibres, further recycling (either mechanically or through depolymerisation) is almost impossible, and therefore downcycled products will likely be disposed of through incineration, rather than the material being cycled several times.

Depolymerisation: the bonds between monomer residues in the plastic are broken either chemically (hydrolysis or glycolysis), or thermally, generating monomers which can be used in raw material production – these processes can also be referred to as monomerisation. These processes are generally quite intensive; however, virgin plastic can be produced from the end-products without the material quality degradation associated with mechanical recycling. Additionally, contaminants can be removed during processing, which is much more challenging in mechanical recycling. Depolymerisation is required in order to cycle plastics permanently once it has reached the point that it can no longer be effectively recycled mechanically, although plastics should undergo multiple mechanical cycles prior to regeneration. Currently, polyamide-6 is the only carpet fibre which is widely recycled chemically, notably by Aquafil. Glycolysis technology is employed for PET bottle recycling in Japan[102], although this technology has not been commercialised on a large scale in Europe. Some chemical recycling of PU exists, although this is fairly rare (for PU, this is < 1 % of the total waste recovered in the EU per year)[103]. PVC and PP are highly chemically resistant, and currently plastic-to-plastic depolymerisation is not used for these materials.

3.2.1 Impact of Chemical Additives on Recycling

The collection and sorting of plastics is very important in the recovery process and, consequently, has a strong influence on overall recycling rates: to illustrate, a small amount of PVC contaminant present in a PET recycle stream will release thermal decomposition products that change the temperature at which PET must melt and thus impacts PET's recyclability [104]. This is true of many chemical additives, including surface treatments, in plastics as they have the ability to change melting temperatures, consistency, strength, brittleness - all which impact quality of end product.

When plastics are first designed, they are designed to impart a particular function such as strength and durability. The use of chemical additives is often essential to achieve this functionality and cannot be avoided. By applying design-for-recycling principles to plastics, switching to additives which are less toxic and are more compatible with recycling processes could improve the quality of the recyclate, making them more competitive with virgin material; however, this largely comes down to cost and innovation.

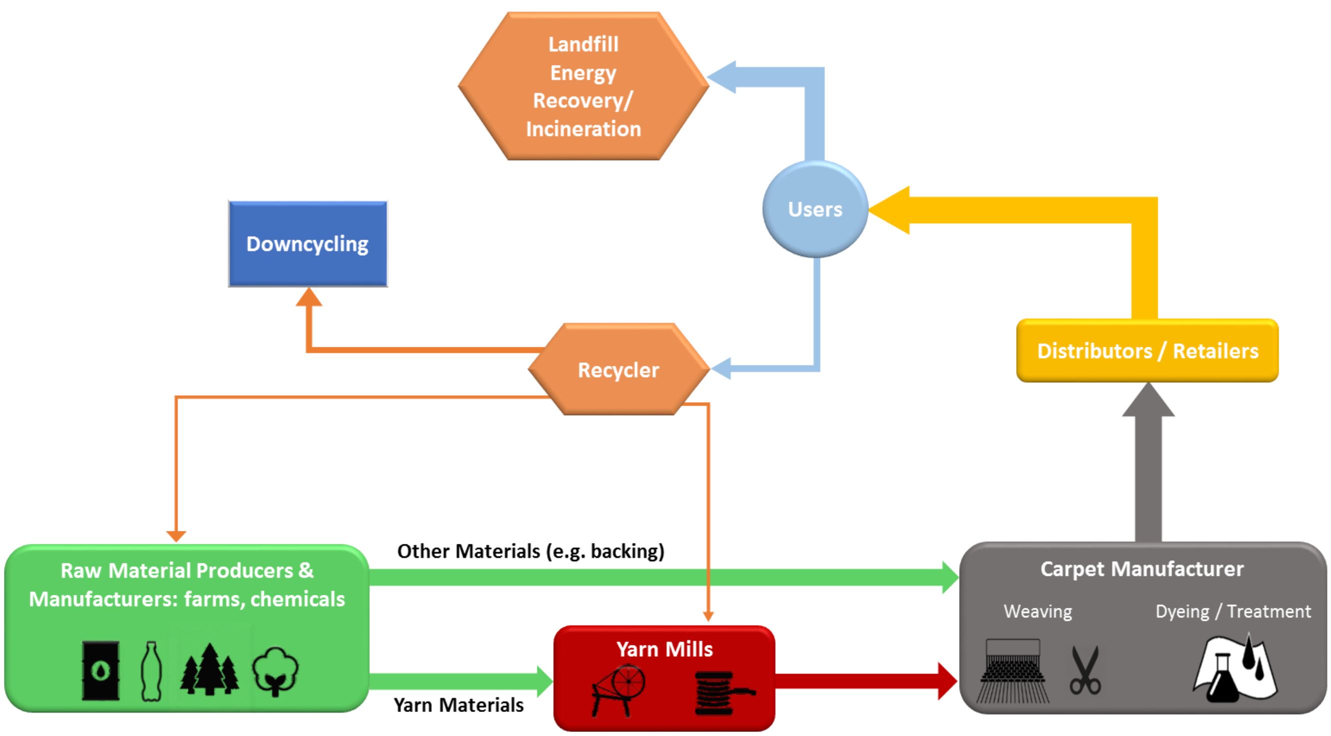
4 Carpets in the EU: Manufacture & Materials

4.1 Carpet Manufacturing Supply Chain

As with any product, toxic substances can be incorporated at any stage of the supply chain. Manufacturing supply chains are often highly complex with several different suppliers and manufacturing facilities, and in some industries there is little transparency. However, carpet supply chains are somewhat more straightforward than some other sectors within the textile industry, and therefore changes to manufacturing practice may be more straightforward to implement. A diagram of a typical carpet supply and use chain is provided in Figure 3.

Raw materials manufacture is the most intensive part of the supply chain by environmental impact; additionally, this is a point of entry for some chemicals of concern (*e.g.* antimony, which is present in catalysts for polyethyleneterephthalate (PET) production)[105]. Yarn is produced from raw fibre materials by mills, and there is generally less transparency on the origins of the material and processes at this stage. Some of the higher profile carpet manufacturers use proprietary fibres, such as Aquafil's Econyl PA, or DuPont's Sorona PTT, which makes them somewhat more traceable; however, not all producers will have visibility on the origins of their fibres further upstream than the mill stage. Product certification is becoming more popular for environmentally oriented brands, *e.g.* Oeko-Tex Standard 100[106], which places restrictions on substances used in manufacture. A large proportion of carpets sold in the EU are certified under GUT®, a carpet industry-led certification, which restricts many fewer substances[107].

Figure 3. Typical carpet supply chain.



Carpet end-users will be exposed to dyes, surface treatments used in fibre manufacture, as well as semi-volatile and volatile substances that migrate from carpet backing, such as phthalates and flame retardants. In manufacture, carpets can either be assembled using pre-dyed yarn, or dyed following construction of the carpet face. Pre-dyed yarn can either be bought from mills or dyed by the manufacturer prior to use; in the case where manufacturers dye either yarn or carpet, it gives them much more control over the substances which go into them. Additionally, surface treatments (such as antimicrobials or stain resistance) are often applied during the final stages of manufacturing.

4.2 Materials and Processes

There is a diverse set of materials which are used in carpet manufacture: the most common ones are covered below.

Polyamide, PA (Polyamide): polyamide-6 and polyamide-6,6 are the most popular fibres for face yarn in carpets for both broadloom and tile carpets. Notably, polyamide-6 is the only plastic used in carpet for which chemical recycling (*i.e.* depolymerisation to monomers, followed by condensation back to a polymer) is commercially viable, enabling 'true' regeneration of the material; while this is a fairly energetically and chemically intensive process, it makes polyamide-6 a more permanent material than other plastics which do not have viable depolymerisation routes. Efforts to commercialize the chemical recycling of polyamide-6,6 (a more complex polymer than polyamide 6) have failed.

Polyester (PET): polyester is used both as a face material, and as a primary backing layer in carpets, *i.e.* the layer which the face yarn is tufted into. Some PET esterification[10] processes are catalysed by organotin compounds which may end up trapped in the product in small quantities, which is now regulated by the EU. However, antimony is the most extensively used catalyst in PET production and is currently essential to production[105]. Post-consumer recycled PET is also used in carpets by manufacturers; the recycled content is typically sourced from plastic bottle waste (for example, Eco-Fi[108]). Currently, fibre-to-fibre recycling is not widespread, either by mechanical or chemical means.

Polypropylene (PP): polypropylene is a highly versatile material, and is employed as a face yarn, primary backing, and as a more rigid backing in carpets. Currently, post-consumer recycled polypropylene is not widely available, although one UK producer of events carpets, Reeds Carpets, operates a facility producing PP pellets from its used events carpets[13], [109].

Natural Fibres: wool and jute are the major natural fibres used in carpets – wool as face yarn, while jute provides a 'classic' carpet backing. There are a number of potential hazards associated with wool, as it must be scoured with surfactants prior to use to remove natural oils[110]; additionally, moth repellents are often added as a post-production treatment.

Styrene Butadiene Rubber (SBR): a synthetic latex, SBR is used widely as a bonding layer in carpets, which has been noted as a major barrier to recycling as it hinders separation of backing and face yarns. There are potential hazards with residual styrene (a carcinogen) in SBR from production. Rubber and latex materials (e.g. tyres) have a long history of incineration, and require high temperatures to avoid incomplete combustion [111]. Additionally, several combustion products from SBR are highly toxic, and require both high temperature and excess oxygen environments in order to decompose completely[111].

Polyvinyl chloride (PVC): PVC plays less of a role in carpet manufacturing in Europe compared to the US, but it is most widely used as a backing, either in broadloom or tile carpets. Notably, Interface use pre-consumer recycled and post-consumer recycled PVC as a carpet tile backing in their GlasBac range[112]. There are several concerns around PVC from a toxicity perspective, both in terms of substances used in production, and around the

[10] A major process in the synthesis on the PET polymer

incineration of PVC [113], [114]. PVC incineration is a contentious issue as it lead to dioxin (PCDD/PCDF) formation on burning.[11] While industry maintains that current incineration standards (both for MSWI and cement kilns) are adequate in limiting its release[115], many maintain that the health hazard posed by dioxins and their persistence, the other toxic substances in PVC, and the material's disposal cost far outweigh its in-use benefits[113]. Moreover, PVC presents a hazard during the use phase, as the additives used in processing (such as phthalates) can migrate out of the material over time.

Calcium carbonate ($CaCO_3$): calcium carbonate/limestone provides the bulk of the total weight of carpet sold in the EU. It is used as a filler material, mostly in SBR layers and in bitumen tile backings. In the US, there has been a growth in the recovery of calcium carbonate from carpet through wet processing, which can be used for agricultural applications[116]. However, it is unclear to what extent the material is recovered in the EU; post-incineration, the recovered ash material may be used as a cement filler.

Bitumen: bitumen is the main secondary backing material used in carpet tiles in the EU, and its hardwearing nature enables reuse. Bitumen may be recycled for use in paving and surfacing applications, or into new backing, as well as being a high-density fuel source; however, it has been noted that it can hinder carpet reprocessing in some cases as it can melt during granulation. It is worth noting here, that bitumen (EC No. 232-490-9) is a UVCB[12] substance with traces of hydrogen sulphide and are known to contain higher levels of PAHs. During combustion, bitumen will emit various alkanes and alkenes; additionally, its sulphur content will contribute to SO_x emissions [117].

Polyurethane (PU): polyurethane is used as a secondary backing material for tile carpets. Polyurethane foam is often used a domestic underlayer for carpet providing cushioning. In addition to the number of hazardous substances in PU foam, it is extremely hard to recycle post-consumer polyurethane waste. Hence, the majority of PU underlay padding is produced using rebonded PU foam, which is often from post-industrial sources[118], [119]. On combustion, PU is known to emit various isocyanate compounds; under incineration conditions these are likely to decompose further to hydrogen cyanide, ammonia, and other nitrogen compounds which need to be effectively scrubbed from emissions[120], [121].

Aluminium trihydroxide ($Al(OH)_3$): this is added to polymer backings as a fire-retardant filler, and is a significant contributor to the total weight of carpets placed on the market. The REACH regulation has not identified any hazards associated with this substance presently.

Table 6. End-of-life options available for the major materials used in carpets.

Material	Role	Recycling
PA6 PA6,6	Face Yarn	**Chemical recycling**: polyamide-6 yarn is recycled chemically in Europe **Mechanical Recycling**: post-consumer polyamide recyclate is used in fibre production [122] **Downcycling**: PA is downcycled for use in felts, equestrian surfaces etc.

[11] The WHO notes that high temperatures of over 850 °C (and over 1000 °C for contaminated materials) are required for complete destruction. [255]

[12] substance of unknown and variable composition, complex reaction products, or biological materials

Material	Role	Recycling
PP	Face Yarn Primary Backing	**Downcycling**: PP is downcycled for use in felts, equestrian surfaces etc. **Mechanical Recycling**: there has been development of PP recycling for polymer feedstock (e.g. for plant pots)[123]; Reeds Carpets (UK) claim to recycle PP events carpets into new feedstock[21]. PA/PP blends cannot be separated, and depolymerisation is technically challenging due to chemical resistance[10].
PET	Face Yarn Primary Backing	**Downcycling**: PP is downcycled for use in felts, equestrian surfaces etc. While mechanical PET recycling is well established for other waste streams, there is little-to-no capacity for fibre-to-fibre recycling (mechanical or chemical) or large scale glycolysis in the EU.
Wool	Face Yarn	**Recycling:** the Italian Re.Verso™ programme creates wool yarn from pre-consumer textile waste for apparel[124]; however, it is unclear whether this process can be applied to post-consumer waste. **Downcycling**: can be used for insulation or padding. Additionally, it is valued for horticulture applications due to its high nitrogen content. Cannot be used for equestrian surfaces
SBR Latex	Binder	SBR has been noted as a major obstacle to recycling, although some recyclers are now able to separate it from other materials.
PVC	Secondary Backing	**Mechanical Recycling**: Interface uses recycled PVC tile backings. Recycled PVC is often post-industrial rather than post-consumer. However, PVC backing can be recycled into new backing. Different types of PVC (rigid and flexible) need to be recycled separately, and other plastics recycling streams have very low tolerance to PVC contamination[125]. Recycled PVC used in flooring may come from decades-old cable & wire sheathing scrap, which can contain numerous additives (such as halogenated flame retardants and heavy metal stabilizers)[126]. PVC can be gasified to produce raw materials for chemical production[127].

Material	Role	Recycling
Bitumen	Secondary Backing	Bitumen has been noted as problematic for recycling where tile backings are difficult to separate from the face yarn. **Reuse**: bitumen carpet backings can be reused in some cases[128], [129]. **Downcycling**: post-consumer bitumen can be used in road surfacing and roofing
PU	Secondary Backing (PU) & Cushion Underlay (PU foam)	**Downcycling**: PU foams can be rebonded to produce new underlay padding material. **Chemical Recycling**: While technologies are available for depolymerisation, they have not been commercialized

A number of data sources have been used to quantify the main materials used in supplying the EU carpets market to give an idea of scale. These are summarised in Table 6 below.[13] There are regional variations in the popularity of different carpet types and materials: for example, PP is the dominant material in the UK, accounting for just over 50 % of the market, and wool maintains ~15 % market share[12].

Table 7. End-of-life strategies available for the major materials used in carpets

	Weight Placed on Market				
Face Yarn	37 %	650 kt			
Backing Layers	63 %	1,120 kt			
Total Weight	1770 kt				
Face Material	**Weight Placed on Market**		**Backing Material**		
Polyamide / PA	40 %	260 kt	**PP**	7 %	88 kt
PET	19 %	123 kt	**PET**	8 %	99 kt
PP	23 %	150 kt	**PU**	< 1 %	7 kt
Acrylic	5 %	33 kt	**Latex / SBR**	19 %	237 kt
Natural	11 %	74 kt	**PVC**	2 %	28 kt
Other	2 %	10 kt	**Bitumen**	5 %	58 kt
			Filler (calcium carbonate, $CaCO_3$)	35 %	433 kt
			Aluminium hydroxide, $Al(OH)_3$	17 %	210 kt
			Glass Fibre	< 1 %	5 kt
			Other	5 %	67 kt

[13] Determined figures from i) market data on face material types; ii) backing materials from estimations of market share for different tile and broadloom constructions. GUT EPDs for each type used as basis, cross referenced with ~15-20 other EPDs.

5 What Toxic Substances are Present in Carpets in the EU?

The chemicals in this report are a non-exhaustive list of potentially toxic chemicals known to be found in the life cycle of carpets that may have environmental and human health impacts. The following sections will give an overview of:

1) chemicals commonly found in carpets;
2) the hazards associated with these chemicals;
3) how they are regulated;
4) how they are restricted, banned or allowed for use under certification schemes governing the carpet sector;
5) potential exposures for workers and consumers;
6) potential impacts on various disposal pathways;
7) policy and manufacturer recommendations.

The basis of chemicals identified in this report were first found to be present in carpet through the HBN 'eliminating toxics in carpets report' which information was derived from the Pharos database - an independent comprehensive database for identifying health hazards associated with building products [130] and includes health related hazards associated with chemicals in carpets. These substances were cross-checked for their presence in the EU carpet market using the information ECHA website as well as Member State reports - such as those that can be found on the Swedish Chemicals Agency's (KEMI) website. Substances were excluded or included as a result.

By understanding the various chemicals, their potential hazards, as well as how they are regulated - one can gain a better understanding of what exposure looks like across the carpets life cycle and consequently why toxics in carpets need to be addressed and removed as quickly as possible. The exposure of these hazardous chemicals via inhalation, ingestion and dermal contact is concerning, particularly for vulnerable populations such as infants and small children.

> ***Children are not 'little adults' and their unique biological make-up and behaviours make them particularly vulnerable to the toxic effects of exposure to chemicals, particularly during critical stages in their physical and cognitive development***[131], [132]***. As identified in various parts of this report, exposures can start as early in utero impacting future growth and development. For example, growing concern around endocrine disrupting chemicals continues as increased incidence of breast cancers, abnormal growth patterns, and neurodevelopmental delays continue to arise in children. Accumulating data supports that many adult diseases may actually have fetal origins***[133]***.***

5.1 Plasticisers: Phthalates

Chemical Profile

Phthalates, well known as plasticizers, are a group of chemicals used to make plastics more flexible and many are commonly used in the backing materials of carpets such as PVC, SB latex, and polyurethane [134], [135]. PVC accounts for nearly 90% of all phthalates use [136], [137]. Phthalates can make up 10-70 percent of the weight of PVC [138]. SB latex and polyurethane may contain levels of phthalates as well, although significantly less than what would typically be found in PVC.

There are 6 commonly restricted phthalates found in carpets which include the low molecular weight (LMW) phthalates DEHP, DBP, and BBP. However, the group also includes the high molecular weight (HMW) phthalates DINP, DIDP, and DNOP. These phthalates are some of the most commonly known; many phthalates exist on the market today, most of which are not yet regulated[134].

Hazard Profile

The LMW phthalates DEHP, DBP, and BBP are classified under CLP as being toxic to reproduction, acutely toxic to aquatic life, bioaccumulative, and toxic to human health.

The HMW phthalates DINP, DIDP, and DNOPs are currently not classified in the EU under CLP; however, they have questionable hazard profiles which are being further investigated. Specifically, Denmark has submitted a new harmonized classification and labelling (CLH) proposal for DINP as toxic to reproduction[139]. However, other evidence suggests that DINP may be a potential carcinogen, endocrine disruptor, as well as a developmental toxicant[140], [141].

Again, there are many phthalates on the market today that have not been comprehensively studied in order to determine their toxic effects such as alkylsulphonicpheylester (ASE) and 1-isopropyl-2,2-dimethyltrimethylene diisobutyrate (TXIB) – both of which can be found in PVC, polyurethanes, and styrene-butadiene rubber[134].

Regulatory and Certification Profile

First restricted in the EU in the use of toys and childcare articles, the three LMW phthalates DEHP, DBP, and BBP were later identified as Substances of Very High Concern (SVHCs) and eventually included on the Authorisation list (Annex XIV) in which they were officially banned in 2015, but may remain as legacy chemicals in carpet installed prior to 2015[140], [142].

Despite the ban, waste recycling companies – Vinyloop Ferra, Stena Recycling, and Plastic Plant - were granted an Authorisation in which they are authorized to recycle DEHP back into recycled PVC formations until 2019 for specific downstream uses such as carpet backings [143], [144].

The ban on the LMW phthalates DEHP, DBP, BBP likely accelerated the use of high molecular weight (HMW) phthalates, specifically DINP, DIDP, and DNOP, resulting in what is presenting itself as a regrettable substitution as more hazard data becomes available on these substances uncovering their toxicity potential [110], [111].

Despite the lack of concrete hazard information at the time, and taking a precautionary approach, ECHA restricted the use of DINP, DIDP, and DNOP in toys and childcare articles in concentrations >0.1% by weight[142], [145]. However, the fact these substances are not restricted in carpets is problematic when we consider the amount of time children spend on the floor and their hand to mouth behaviours. It becomes apparent from the information above, either 1) the expansion of these restrictions for HMW phthalates should consider carpet or; 2) provided the Denmark CLH proposal is upheld, the use of DINP (and possibly the other HMW phthalates) should be considered SVHCs and be included on Annex XIV.

The use of these hazardous phthalates such as DINP, DIDP, and DNOP is problematic when we investigate carpet manufacturers with the public perception as being 'sustainable' or 'green' and find they are using these substances in the manufacture of their carpets. Tarkett was granted a Safe Use Determination (SUD) from the state of California for the use of DINP at concentrations less than 9% in PVC carpet backing. Similarly, Interface recently requested a SUD for the presence of DINP in their modular carpet tiles. Should these carpet materials become recycled, they will continue to impact the quality and safety of recycled materials and may find their way into new products such as children's toys.

The aforementioned phthalates are only a subset of the hundreds of phthalates that exist on the market today, some with likely questionable hazard profiles that remain largely unregulated. To compensate for the lack of regulation around these substances, certifications like Blue Angel and Nordic Swan ban the use of phthalates entirely. Moreover, Nordic Swan also bans the use of PVC in carpet materials, significantly reducing the need for phthalates[146].

Exposure Profile

Worker

Carpet manufacturers and installers are highly exposed to phthalates. Workers handling the carpets, backing, or padding containing phthalates have direct skin and eye contact as well as potential inhalation exposure. U.S. biomonitoring studies in the plastics industry have found phthalate metabolite concentrations in the urine of plastic industry manufacturing workers were significantly higher in comparison to community service workers. Workers in the recycling process of plastics, such as PVC, may also be increasingly exposed to phthalates [147]. [111]

Consumer

Phthalates are semi-volatile organic compounds (SVOCs) and can be found in the air by leaching directly from carpet product [148]. Thus, exposure can occur from breathing in phthalate vapours resulting from carpet materials. Also, phthalates are known to adhere to dust. Young children could possibly have a greater risk of being exposed to phthalates in dust than adults because of their hand-to-mouth behaviours [149], [150].

Additionally, phthalates may enter the environment in industrial waste waters from manufacturing sites and pose a risk for aquatic and terrestrial ecosystems and surrounding community.

Disposal Profile

Landfill

Phthalates may enter the air from disposal sites, as well as leach into soils and water including the groundwater – leaching of phthalates from landfill is well documented[151]. Phthalates may also be deposited into the soil and water by rain. Phthalates may be degraded biologically, but this is a multi-stage process and requires several different species of bacteria and appropriate treatment conditions (e.g. presence of sludge)[152].

It has been noted that DINP may persist in water for several weeks if it is discharged into waterways without prior treatment[153].

Incineration

Thermal decomposition of phthalates is not well known and depends on the substance functional groups and structure. However, since phthalates are found in PVC and other plastics, understanding the thermal decomposition products in these materials is worth considering as they get sent to incineration[154], [155]. Additionally, in the heating process thermal decomposition products of phthalates may be released, further exposing workers[156].

Recycling

The recycling of phthalate containing plastics such as PVC requires mechanical separation, grinding, washing, treatment, and then reuse in the production process. This production process may make phthalates airborne and waterborne exposure also becomes possible[157]. This also means that phthalates can continue to persist in the recyclate materials. However, the currently limited use of recycled PVC sold in Europe carpet likely means they will not get sent to recycling and instead be sent to be incinerated.

Recommendations
Policy makers: Should Denmark's harmonised classification and labelling (CLH) proposal be upheld, Di-iso-nonyl-phthalate (DINP) should be considered a SVHC, included on the Candidate list and be subject to Authorisation.
Manufacturers: Manufacturers should transition away immediately from the use of PVC in order to significantly reduce the need for phthalates and move towards PET and polyolefin (polyethylene and polypropylene[158], [159]) plastic materials as they do not generally require the use of plasticizers. However, to give them strength and durability and other performance properties, polyolefin plastics may use other chemical additives (such as halogenated flame retardants) and therefore these chemicals should be chosen on the basis of how they impact human and environmental health across the life cycle as well as recyclability of these materials. Should PVC carpet backing be required for some reason, manufacturers at a minimum should transition away from the use of phthalates by requesting the use of non-toxic phthalate free plasticisers to best avoid regrettable substitutions.
Consumers: Only purchase carpet indicated by the manufacturer as 'phthalate-free' and avoid carpet made with recycled PVC, as these materials are usually contaminated with phthalates.

5.2 Alkyphenol Ethoxylates: Nonylphenols (NPs) & NonylphenolEthoxylates (NPEOs)

Chemical Profile
Alkylphenol ethoxylates (APEs) are a group of non-ionic surfactants used in a wide variety of industrial applications and consumer products. Approximately 90% of the APEs produced are nonylphenol ethoxylates (NPEs) and are included in the carpet industry within cleaning, dyeing, and rinsing agents, as well as used within detergents in wool scouring where natural oils are removed from the wool and other textile fibres. While their commercial use in cleaning agents and detergents has largely been phased out in Europe owing to their hazard profiles, they are still used in the EU as adhesives in carpet backing.

Hazard Profile
Alkyphenol ethoxylates are themselves believed to be endocrine disruptors and to cause feminisation of male fish. However, it is their metabolites which are often more potent as endocrine disruptors than the parent compounds[160].

Specifically, NPEs are toxic to aquatic organisms and degrade into the more environmentally persistent, moderately bio accumulative and extremely toxic nonylphenols (NP). This persistence in the environment has also shown the potential impact on animals (particularly fish) in the form of reproductive disorders, endocrine disruption, feminization of males, birth defects, and significant population reduction[161]–[163]. NP is categorized under CLP as a reproductive toxic 'suspected of damaging fertility and causing harm to the unborn child'[164], [165]. NP may also be used as an intermediate for the use as a heat stabilizer [166] and antioxidant in plastic and rubber materials[167].

Regulatory and Certification Profile
In 1976, the UK had a voluntary agreement with industry that NPEs would not be added to domestic detergents, and this has been more widely agreed upon across Europe since[168]. Despite known hazards and industry concerns for over 40 years, NPEs have only recently become more heavily regulated.

Since 2016 NPEs are restricted under Annex XVII to REACH by 2021 in concentrations >0.1% by weight of textile article which can reasonably be expected to be washed in water during their normal life cycle[169], [170]. This restriction, however, does not apply in the following cases:

- Textile processing with no release to waste water.

- The placing on the market of second hand textile articles.
- New textile articles produced, without the use of NPE, exclusively from recycled textiles. In other words, recycled textiles could have NPEs irrespective of whether NPE was used in the manufacture of the new, yet recycled, textile.

As part of this restriction, textile article is defined as, “means any unfinished, semi-finished or finished product which is composed of at least 80% textile fibres by weight, or any other product that contains a part which is composed of at least 80 % textile fibres by weight, including products such as clothing, accessories, interior textiles, fibres, yarn, fabrics and knitted panels.”

NPEs as a class of substances were placed on the Candidate list in June 2017. 4-nonylphenol, branched and linear, ethoxylated, which are used as intermediates in the manufacture of substances used in detergents, plastics, and adhesives were specifically added to the Authorisation List (Annex XIV) and given a sunset date of January 2021 displacing a significant amount of NPEs currently on the market[171].

Despite the restrictions and bans currently in place in the EU on NPEs, imported articles may still contain these chemicals as it is unclear how the potential presence of SVHC substances in article imports is enforced.

Exposure Profile

Workers

Since NPEs are generally used as commercial detergents they can be found on the surface of the carpet. Carpet manufacturer workers or installers are exposed to NPs/NPEs during the handling of chemical preparations and/or when in contact with treated carpets. Exposure includes dermal and inhalation pathways. The use of NPs/NPEs in the carpet manufacturing process leads to waste water discharge into the surrounding community. This is an issue because NPs and NPEs are considered high volume chemicals and highly toxic to aquatic organisms[164].

Consumer Use

The general population is exposed in a number of different pathways – including both ingestion and dermal. NP has been found in breast milk from German women at levels of 0.3 µg/kg[172]. During consumer use, general carpet cleaning may uptake residual amounts of NP/NPEs found on the carpet and discharge them back into the water stream. When we consider all the homes in Europe cleaning their carpets containing NP/NPEs and sending waste water into the environment, the seemingly insignificant amounts can actually create a compounding impact given the persistence of these substances.

Disposal Profile

Landfill

Residual amounts of NP/NPEs can find their way in landfill leachate. These chemicals are difficult to process and have been found in waste water and sewage treatment plant effluents[163].

Incineration

Thermal degradation products may include volatile products such as acetaldehyde, formaldehyde, glycol ethers, ethylene glycols, 1,4-dioxane, acetone ethanol, and the residual starting nonylphenol[173].

Recycling

NP/NPEs can end up in recycled textiles. Because recycling generally requires the heating/melting of the polymeric substance these NPEs are treated on, the thermal degradation products of NP/NPEs may also be present in the recycled material. Little information exists indicating whether NP/NPEs could be removed from recycled materials.

Recommendations

***Policymakers**:* The current Restriction of NPEs in textiles should provide better guidance as to whether carpets – both broadloom and tile - fall within this restriction. If not, their inclusion to this restriction is recommended. The restriction should also include NP/NPE as used in adhesives for carpet backing. Additionally, end-of-life textiles including carpet should include testing for the presence of NPEs to guarantee safety of collectors, recyclers, and other workers. This is important when dealing with legacy issues prior to the impact of the Authorisation and Restriction initiatives on NP/NPE.

***Manufacturers**:* The use of NPEs as auxiliary chemicals in the cleaning of textiles such as carpets during their manufacture and their presence in the finished product highlights the need for manufacturers to transition away from hazardous chemicals such as NPEs throughout the manufacturing process. This should be done ahead of any impact from the regulatory initiatives highlighted above.

5.3 Biocides: Antimicrobials

Chemical Profile

A biocide is defined in the EU legislation as a chemical substance or microorganism intended to destroy, deter, render harmless, or exert a controlling effect on any harmful organism by chemical or biological means. Biocides (specifically antimicrobials) used in carpets provide a level of protection against dust mites, moulds, bacteria, fungi and are used in the treatment of carpet fibres and backings. Wool carpets are particularly susceptible to the use of biocides, such as permethrins, given wool is a natural fibre and requires treatment in order to avoid the growth of certain bacteria. Equivalently, plastics are carbon-based materials and also require the use of preservative anti-microbials in order to prevent microbes from destroying them. In the EU, the leading biocide sales for textiles include silver, silane quats, and other quaternary compounds[174]. Some additional antimicrobials used in carpet materials include formaldehyde, permethrin, 10,10'-Oxybisphenoxarsine (OBPA), isothiazolones, zinc pyrithione (ZPT). and 3-iodo-2-propynyl butylcarbamate (IPBC)[175], [176].

A 2016 market survey performed by the Swedish Chemicals Agency on articles treated with biocides identified silver, triclosan (Microban®), and organotin compounds as possibly found in carpets[177].

Silane quats and other quaternary ammonium compounds are also commonly used antimicrobials in textiles. The use of silver and silane quats is expected to increase in textiles over the years while the use of biocides such as OBPA is expected to decrease[176].

Hazard Profile

Many biocides are designed to kill one or more target organisms. These organotoxicants can also be poisonous to humans as well. The hazards for biocides used in carpets range from mild eye and skin irritants to skin sensitizers to reproductive toxicants [178].

Silver, particularly nano-silver, and its potential health impacts are largely not understood presently. On-going research governing the safety of nano-materials continues in Europe and globally.

Permethrin is classified by the US EPA as a “likely to be carcinogenic to human” in addition to recognizing permethrins ability to alter nerve function. In non-cancer risk estimates for toddlers exposed to permethrin treated carpets were above EPAs level of concern (LOC). Cancer risk estimates for adults exposed to indoor surfaces treated with permethrin were above EPAs LOC[179], [180]. Permethrin is not classified in the EU under REACH as a carcinogen, but rather as aquatically toxic and skin sensitizing[181]. Additionally, permethrin, is highly toxic to bees[182].

Isothiazolinones have hazards associated with them such as being toxic to aquatic life as well as causing skin irritation and sensitization[183]. In addition to these hazards, MIT is listed in Annex III as a suspected carcinogen[184].

ZPT has been recognized as skin sensitizer, toxic to reproduction, as well as exhibits specific target organ toxicity, among other hazards[185]. IPBC is also a skin sensitizer as well as suspected to be an endocrine disruptor in addition to being very toxic to aquatic life[186].

Regulatory and Certification Profile

Biocides are regulated in the EU under the European Biocidal Product Regulation (BPR). The BPR "aims to improve the functioning of the biocidal product market in the EU, while ensuring a high level of protection for humans and the environment." All new biocide active substances and their use in specific product types must be approved by BPR before being placed on the market unless still under assessment and Authorisation has been granted[175]. Approval of a biocide does not mean the biocide is non-hazardous, but rather that it's use in a particular product-type is an acceptable use[187].

The legislation (article 5.1) foresees that several categories of substances such as endocrine disruptors with adverse effects on human health, PBT or vPVB substances, substances classified as mutagens 1A/1B or substances classified as toxic for reproduction (1A/1B) shall not be placed on the market in biocidal products. However, derogations are possible in certain circumstances (article 5.2). Due to the delay in the process of definition of identification criteria for endocrine disruptors for pesticides and biocides, the ban on endocrine disruptors with adverse human health effects will apply from June 2018. It remains to be seen how effective the criteria will be in order to regulate endocrine disrupting biocides with an adverse effect on human health, especially in the light of the possibility for derogation mentioned above[188], [189].

Silver, as a biocide, is currently under review for the use in textiles, including carpet fibres, with the purpose of producing treated articles with disinfecting properties. However, silver has not yet been reviewed for use as a preservative/antimicrobial for the preservation of fibrous or polymerized material, such as rubber or textile products nor used for the preservation of films or coatings such as plastics, sealants, or adhesives[55]. Therefore, companies using silver in these types of products cannot make claims of having antimicrobial properties.

However, companies may add chemicals which are consequently biocides, such as 'nano-silver', to their carpets without the intention of it using nano-silver for its antimicrobial properties – yet benefit from the inhibition of microbes. This way, companies can make claims that they do not add biocides to their product. This means these carpet manufacturers also do not need to report as having a biocide treated article nor adhere to specific biocide labelling requirements.

Triclosan is banned in the EU and should not be found as an antimicrobial in any application. Permethrin is banned in the EU for agricultural purposes but has approved uses in non-agricultural applications for the use of controlling insects by means other than repulsion or attraction. Treated articles with permethrin should be properly labelled as having the potential to be skin sensitizers[53].

Despite many articles treated with biocides requiring labelling in the EU, most consumers are likely unaware that biocides are found in the treatment of their carpets. An assessment conducted by Sweden concluded that only 18% suppliers of articles containing biocides had information about the active biocide substance labelled. However, in all cases the required information as defined in the BPR was incomplete or missing[177], [190]. This continues to be large issue for imports.

Many of the isothiazolinones, such as MIT, OIT, DOIT, are either approved or under review for use in many product types under the BPR regulation[191], [192]. The presence of the carrier phthalates are of concern in the Vinzyene® products[193]. Even if these phthalates are found in residual amounts in textiles as carriers of the isothiazolinones, they could pose a potential issue given phthalates are part of the potential CMR restriction in textiles.

When possible, the best biocide to use is none. In fact, the Nordic Swan eco-label limits the use of isothiazolinones to 500 ppm, CIT/MIT mixtures to 15 ppm, and MIT to 200 ppm and has banned the use of all other biocides.

Exposure Profile

Worker

The wet processing of wool fibres requires the use of Permethrin in order to protect the wool. Biocides incorporated in the carpet manufacturing process may be exposed to workers via inhalation as well as skin/eye contact in the handling of products containing biocides. As with many manufacturing operations, there is always potential for worker exposure. If there is not a waste water collection in the textile process, these biocides are released into the surrounding waters. Therefore, minimizing use and exposure to the environment is essential.

Consumer

Approximately 90% of biocides found in textiles are coating treatments and not bound to the textile fibre. Therefore, these substances may be exposed to consumer via inhalation and skin/eye exposure.

Disposal Profile

Landfill

Owing to their antimicrobial properties, biological degradation of these biocides tends to be limited. As a consequence of variation in leachate treatment practices for MSW, it is likely that these will be released into the environment. For example, IPBC requires alkaline conditions in order for hydrolysis to less toxic metabolites to occur and remains stable in acidic leachate[194]. While some of these substances have been shown to be successfully decomposed using photolysis or other free-radical based treatment (*e.g.* with ozone), this will not always be applied[195].

The use of silver and silver nanoparticles is of concern as these are unlikely to be filtered out of leachate during treatment due to their size, and these will persist in the environment[196].

Incineration

When biocides are incinerated, compounds such as polychlorinated dioxins, furans or other halogen compounds can be formed. Therefore, the BPR guidance recommends specific incineration conditions such as temperature, reaction time and oxygen content for safer incineration of biocidal waste be provided. Carpets and other articles treated with biocides do not fall within the scope of this guidance yet their incineration may in fact emit these substances[197]. Incinerator guidelines in the EU are in place to control dioxins and other toxic decomposition; however, there is still a possibility that these may be released into the environment. .

Recycling

Biocides, like many additives, may destroy the integrity of the polymer during the recycling process making the end product variable. Biocides may also persist in downcycled material. This is particularly concerning when post-consumer yarn is used for equestrian or horticultural applications, as this would provide a direct route for release of these substances into the environment.

Recommendations

Policymakers*:* Biocidal Product Regulation should be expanded to oblige notification of any biocide used in the manufacture of carpet even when not intended for antimicrobial use. Stricter enforcement on imported articles is necessary to ensure carpets treated with biocides are properly labelled when relevant.

***Manufacturers**:* Carpet manufacturers need to ensure their use of the biocide antimicrobial is necessary and avoid the use when possible. Additionally, they must properly label their carpets as containing biocides when making claims of antimicrobial properties.

5.4 Flame Retardants

Chemical Profile

Flame retardants are chemicals added to materials to slow or prevent the start or growth of fire. Flame retardants are used in a number of consumer products. They are heavily used in carpet material such as plastic materials and polyurethane foam (carpet padding). These flame retardants can be 'reactive' where they are bound to the material or 'additive' where they are exposed and can migrate. Typically, in the products found in carpet, they are additive and thus, able to migrate from carpet materials. There are hundreds of different flame retardants on the market which are often categorized based on their chemical structure - with halogenated and organophosphorus flame retardants being the two most common classes of flame retardants[198], [199].

Halogenated flame retardants are probably the most universally known class of flame retardants and include polybrominated diphenyl ethers (PBDEs), tris-(2-chloroethyl) phosphate (TCEP), as well as other brominated and chlorinated flame retardants.

Non-halogenated organophosphorus flame retardants have been identified as replacement flame retardants. This class of flame retardants continue to attract scientific research to track human exposure through the environment given their use as a replacement for halogenated flame retardants and antimony trioxide[200].

Hazard Profile

Many of the ubiquitous halogenated flame retardants have been removed from the market or are no longer produced because of their hazard profiles. Halogenated substances typically do not break down easily in the environment and can remain persistent and bioaccumulate in the environment for years. Many of these flame retardants are linked to neurological effects, endocrine disruption, decreased fertility, lower birth weights, as well as developmental and cognitive problems in subsequent generations[201], [202].

A U.S. study reported that exposure to specific PBDEs was a risk factor for acute lymphoblastic leukaemia (ALL) - a common childhood cancer. The study indicated that house dust was a major contributor and risk factor to PBDE exposure[203]. Despite being banned in much of the world, PBDEs are still being found in products and dust[204].

The hazards associated with non-halogenated organophosphorus flame retardants, such as tricresyl phosphate (TCP), are still being understood and studied. Current research suggests they may be persistent, bioaccumulative, and toxic as well as have endocrine disrupting properties. An alternative assessment conducted by U.S. EPA for flame retardants in PU, showed that TCP may have significant hazards such as reproductive toxicity as well as potential developmental and neurological effects[205].

Regulatory and Certification Profile

Halogenated flame retardants have garnered regulatory attention owing to their hazard profiles and uses in a variety of products. Many polybrominated diphenylethers (PBDEs) – specifically pentaBDE and octaBDE have been banned in the EU since 2004. DecaBDE has been banned for use in electronics in 2008. However, decaBDE is still used in the textile sector[206]. In 2012, DecaBDE was added to the Candidate list but has not yet been placed on the Authorisation list and given a sunset date. In February 2017, the European Commission published a restriction on the use of decaBDE in textiles in concentrations equal to or greater than 0.1% by weight[207].

At that international level, pentaBDE and octaBDE are listed under the Stockholm Convention on Persistent Organic Pollutants (POPs) since 2008. The EU's proposed restriction on decaBDE is significant because it may impact how decaBDE is controlled globally through the Stockholm Convention. In fact, decaBDE was recently requested to be banned under the POPs convention as well. However, textile exemptions have been proposed that would allow the use of decaDBE in textiles like carpets. Under the POPs agreement for these brominated flame retardants, recycled materials containing these substances are exempt and may continue to be present in recycled materials until 2030[208]. According to UNIDO, "DecaBDE can degrade in thermal processes, environmental processes and in biota to polybrominated dibenzofurans and, depending on conditions, polybrominated dibenzo-p-dioxins" which are known carcinogens, leaving recycling workers particularly susceptible to their toxic effects.

Despite many halogenated flame retardants being restricted and/or banned, their presence is expected to show up in recycled materials. Therefore to ensure the highest level of consumer safety, the same ban/limit should extend to these recycled materials as these recycled materials may be used to produce future products and consumer goods.

The EU's Toy Substance Directive has set a flame retardant limit for TCEP*, TCPP, TDCP of 5 mg/kg. This limit does not currently exist for other products in which flame retardants may exist, including carpet. However, ECHA has recently requested further information on these flame retardants to support a possible restriction[209], [210]. ECHA identified a risk to children exposed to TCEP, TCPP, TDCP in polyurethane foams found in childcare articles and furniture. ECHA has stated that the proposal may go beyond these products[211], [212]. According to ECHAs documentation, the use of these flame retardants is likely driven by member state fire safety regulations and limited experience with use of alternative flame retardants[200].

The hazards associated with halogenated flame retardants has led to other non-halogenated phosphorus-containing flame retardants. Non-halogenated phosphorus flame retardants are currently of particular interest to many research scientists because their potential hazards are not yet fully understood. However, there is growing concern many may be endocrine disruptors as well as persistent, bioaccumulative, and toxic. Some of these non-halogenated phosphorus-containing flame retardants include components of Firemaster 550® such as triphenyl phosphate (TPP) and isopropylated triphenyl phosphate (IPTP). The U.S. Environmental Protection Agency is considering restrictions on TPP under the Toxic Substances Control Act[213].

The aforementioned flame retardants are just some of the most notorious and well known. There are still other less known, yet just as hazardous, flame retardants on the market that will continue to be used in the marketplace in the manufacture of carpets.

Exposure Profile

Worker

A technical bulletin published by the state of California in the U.S. stated that studies have shown polyurethane (PU) foam recyclers and carpet installers, as well as carpet pad factory workers have shown elevated levels of flame retardants in their tissues[214].

An often overlooked group of workers exposed to the toxic effects of the thermal decomposition of the chemicals are firefighters. The National Fire Protection Association (NFPA) has stated that most fire deaths are not caused by burns, but by toxic smoke inhalation. Toxic gases include carbon monoxide (CO), hydrogen cyanide (HCN) which results from the burning of plastics such as PVC, as well as the release of phosgene which can lead to pulmonary edema and lead to death. A UK study found that while flame retardants reduce fire growth rate, they increase the toxicity of smoke producing significantly greater quantities of CO and HCN.

Consumer
Like many of the chemicals in this report, flame retardants can migrate out of the carpet and become part of household dust that can be inhaled or ingested. The National Institute of Environmental Health Sciences notes, "Research has found children typically have higher concentrations of flame retardants in their bodies than adults"[215].

Disposal Profile
Landfill
Textiles are a large source of flame retardants. Flame retardants can be difficult to manage in landfill leachate and sludge. In many countries, landfill leachate is allowed to be disposed of in municipal waste water treatment plants. These conventional waste water treatments are inefficient in the removal of many organic pollutants, thus making many municipal wastewater treatment effluents considered a major source of pollution[216], [217]. Some substances (such as decaBDE) have been found to undergo photolysis under UV light, but some of the degradation products are also hazardous to aquatic life, and leachate may not receive this type of treatment[218]. For several consumer products, there has been a shift towards phosphate-based flame retardants which can undergo biological degradation, although this is highly dependent on treatment conditions[219], [220].

Incineration
Depending on the specific compound and functional groups making up the flame retardant, thermal decomposition products could vary. However, brominated and chlorinated flame retardants could release hydrogen bromide/chloride respectively upon thermal decomposition, which can lead to dioxin formation. However, incineration is different to thermal decomposition in that the process of incineration transfers many of these thermal decomposition products into tolerable emissions, such as Nx, which have acceptable emission rates at the incineration stacks.

Recycling
Flame retardants are frequently discussed in the EU circular economy debate, with officials on both sides debating against the trade-offs between consumer safety from toxic substances in recycled products and resource efficiency. There is much evidence showing that banned polybrominated diphenyl ethers are still being found in recycled plastic products. In a recent study of children's toys made from recycled products from 26 different countries, found that 90% of the samples contained banned octaBDE and decaBDE.

Recommendations
Policymakers: Avoiding the use of halogenated flame retardants should be the priority in carpet products as safer alternatives already exist. The current Restriction on DecaBDE should be closely monitored for sufficiency in this regard. As part of a phased approach, there should also be efforts to accelerate the possible restriction on the use of TCEP, TCPP, TDCP and extend this restriction to include their use in polyurethane materials. These restrictions should also extend to recycled materials. There is a strong case for alignment with the Toy Safety Directive in view of the similarity of exposure routes.
Manufacturers: While slowing the growth rate of fire, the use of hazardous flame retardants may have toxic consequences; therefore, the use of less hazardous flame retardants should be used in order to meet the necessary fire protection regulations. The Blue Angel certification recommends the use of ammonium phosphate or

expandable graphite. Additionally, avoid the use of recycled and bonded polyurethane foam for the use of carpet padding as these are likely to contain high amounts of hazardous flame retardants.

5.5 Stain Repellents: Per- and polyfluorinated alkyl substances (PFAS)

Chemical Profile

Per- or polyfluoroalkyl substances (PFASs) is a term used to refer to a group of toxic synthetic chemicals including perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), and many others. These PFAS substances have historically been used as stain repellent finishes for many textiles, including carpets[221].

Historically, industry used long-chain PFAS, which includes PFOA and PFOS. However, a cascade of studies revealed the toxic impacts of long-chain PFAS resulting in most companies switching to their short-chain counterparts, which were less studied[4].Since the change to short-chain PFAS, subsequent studies have shown their hazards to be similar to long-chain PFAS, resulting in one of history's most notorious regrettable substitution stories.

The PFAS class contains thousands of chemicals, not just PFOA and PFOS. Other PFAS include but are not limited to perfluorohexanesulfonic acid (PFHxS), perfluoronic acid (PFNA), perfluorodecanoic acid (PFDA), Perfluoroundecanoic acid (PFUnDA), perfluorododecanoic acid (PFDoDA), perfluoroethridecanoic acid (PFTrDA) and perfluorotetradecanoic acid (PFTeDA). Again, many of these are structurally similar and may possess similar hazards. In an effort to eliminate this class of chemicals all together, Tarkett recently announced its fluorine-free soil protection technology[84].

Hazard Profile

PFOS, and its derivatives, is known to be a persistent organic pollutant (POP)[222]–[224]. POPs are organic chemical substances that persist in the environment, bioaccumulate through the food chain, and pose harm to human and environmental health[225], [226].

PFOA, its salts and related substances are expected to have a similar hazard profile as PFOS. In fact, both PFOS and PFOA are regarded in the EU as suspected carcinogens, toxic to reproduction, and may cause developmental disorders as these substances persist in the tissues of organism.
Short-chain PFAS are similar to their long-chain counterparts in that they transform in the environment to their often highly persistent perfluorinated acid. Short-chain PFAS are more soluble and less likely to bioaccumulate and are also more likely to be transported long distances in water. Long-chain PFAS are generally more persistent and more likely to bioaccumulate in living organisms[227].

It currently appears that long-chain PFAS are more hazardous that short chain PFASs, however, hazards associated with short chain PFASs are not well documented and some exceptions may apply. For example, some studies show that PFHxS [short-chain PFAS] comes close to liver toxicity when compared to the toxic effects of long-chain PFAS. In some studies, it appears that short-chain PFAS may have higher endocrine disrupting potential than long-chain PFASs[227].

Many other PFAS also share similar chemical properties and consequently toxicity[228]. It appears more understanding of this class of chemicals is shedding light on the similarities of all PFAS.

Regulatory and Certification Profile

PFOS were originally added to EU's restricted substance list Annex XVII and later removed and added to Annex B of the Stockholm Convention list of Persistent Organic Pollutants (POPs) in 2009. Under POPs, all uses of PFOS should be prohibited in the EU, however, not all are completely banned. In fact, the approved limit for textiles or other coated materials is 1 µg/m^2.

In 2014, PFOA was added to the Candidate List of substances. More recently, PFOA was added to the EU's restricted substance list, Annex XVII. Beginning 4 July 2020, PFOA will not be allowed to be used in the production of or placed on the market in another substance as a constituent, mixture, or an article in a concentration equal to or above 25 ppb of one or 1000 ppb in a combination of PFOA-related substances[143], [229]–[231]. However, the restriction and limits do not apply to textiles, until 4 July 2023. It is unclear, as textiles are not defined in the restriction, as to whether carpets must adhere to the 2020 or 2023 restriction deadline. Despite similar hazard profiles, only PFOS and its derivatives are currently on the Stockholm Convention list of POPs, although PFOA is currently being considered for inclusion[232].

Norway has proposed that perfluorohexane-1-sulfonic acid (PFHxS) also be added to the POPs list[233]. Germany and Sweden have proposed restrictions on six other PFASs perfluoronic acid (PFNA), perfluorodecanoic acid (PFDA), Perfluoroundecanoic acid (PFUnDA), perfluorododecanoic acid (PFDoDA), perfluoroethridecanoic acid (PFTrDA) and perfluorotetradecanoic acid (PFTeDA) as well as their salts and precursors with a concentration limit of 25 ppb. The proposed restriction also extends to restricted related substances at 260 ppb, thus including several hundred PFASs in its scope[234], [235].

Many member states have researched PFAS and their alternatives to assist industry in finding an alternative solution as PFAS are restricted and banned across the European Union. Denmark published a report on 'Alternatives to PFAS in textiles' in 2015. Similarly, Sweden published a detailed report discussing the various uses of PFASs as well as an overview of alternative substances, materials and technologies. Tarkett announced in December that it was PFAS-free joining fiber manufacturers such as Aquafil and Universal Fibers which off PFAS-free carpet yarn[75].

Certifications such as Nordic Swan and Oeko-Tex have set standards for PFOS and PFOA to be <1% µg/m [106], [146], while the GUT label bans their use entirely. It remains unclear, as testing criteria are not easily found, as to whether this zero-tolerance ban is adhered too. In research of GUT approved labs, it appears there is a required test for heavy metals, plasticisers, biocides, pesticides, and POPs substances – but does not specify the test or if PFOAs are also covered in their testing parameters. Oeko-Tex does further restrict the use of certain other PFAS in carpets, however, given the broad scope of the class of chemicals not all are captured.

Exposure Profile

Worker

According to the U.S. Department of the Navy, workers involved in the production of PFAS or PFAS containing carpets are some of the most likely populations to be exposed via inhalation and to a lesser extent dermal and oral routes of exposure[236]. However, higher levels of PFAS can be found near areas where they are manufactured or where products containing them are manufactured.

Consumer

PFAS move easily in the environment and have been found in soil and water samples far from discharge sites, consequently making their way into drinking water. Because of their inability to break down, these persistent chemicals have also been found in the blood of humans. The persistence of PFAS in human blood can also exposure unborn children to PFAS. Women's breast milk has been tested with positive findings of PFAS, consequently exposing infants. Additionally, it has been identified that the uptake of PFOA is higher on a body weight basis compared to adult, partly due their hand-mouth behaviours from treated carpets and ingestion of

PFAS contaminated dust[237]. To better understand the risks these chemicals have on human health, PFASs are one of the class of compounds currently under Europe's Human Biomonitoring Programme.

Disposal Profile

Landfill

Once carpets are landfilled they have the ability to leach from the carpet. The Swedish Environmental Protection Agency (KEMI) shows in its screening from 2016 that 'leachate from landfills may be an important source of PFAS in the environment'[235]. Across the globe, PFASs appear to be found in most leachate samples and may enter soil and groundwater. Like at manufacturing discharge sites, once PFASs enter the ground water they can travel significant distance without breaking down and persist in the environment and tissues of living organisms[225], [238].

Incineration

Not much research exists regarding the thermal decomposition of PFASs. PFASs require high temperatures for decomposition, and they have been used extensively in fire-fighting foams. Current guidance recommends that these compounds are incinerated at >1000 °C; MSW incinerators in the EU have a minimum requirement that flue gases reach 850 °C for 2 seconds, and therefore PFASs may not undergo complete degradation by this route and may persist, depending on the operating standards used by the facilities[225].

Recycling

PFASs can find their way into recycled and downcycled material – as PFASs are widely used in face yarn, they may persist in applications such as insulation and equestrian surfaces (which provides a direct environmental leakage point). The continued restriction and ban on PFASs will continue to reduce the availability and risks of these chemicals in carpets.

Recommendations

Policymakers*:* The current REACH restriction on PFOA should be more specific on textiles and ensure the use of PFOA is phased out of carpets and their constituent materials no later than 2020. This restriction should go beyond PFOA to include all PFASs, and at minimum include those PFAS identified by Sweden. Other member states should work in collaboration with Sweden to identify additional PFASs that should be included in this Restriction. Additionally, Member States should submit classification proposals identifying these substances as SVHCs, where not already done, so that they may be added to the Candidate List for inclusion on the Authorisation List[235].

Manufacturers*:* If carpet manufacturers haven't already done so, they must begin the phasing out of PFAS and related substances immediately and look towards the use of non-fluorinated alternatives. Additionally, manufacturers should do their due diligence to avoid regrettable substitutions by removing all PFASs from carpets. Since the chemistry of water repellence is challenging, more innovation around stain repellence in carpets is needed and therefore, industry should find ways to innovate collaboratively.

5.6 Heavy Metals & Metal Compounds

Chemical Profile

Heavy metals are used in carpet as metal complex dyes, pigments, mordants, catalysts in synthetic fabrics or carpet backing, synergists of flame retardants, antimicrobials, water repellents, or odour prevention agents. Some of these heavy metals can be highly toxic and include lead (Pb), cadmium (Cd), and mercury (Hg)[239]–[242].

Organometallic chemicals such as organotin compounds, are used as heat stabilizers in polymeric materials such as polyurethane foam, polyester, as well as PVC carpet backings. Outside of their use as a heat stabilizer, organotins may be used in many textiles treated with biocides may contain organotin compounds as they can have biocidal properties for their biocidal properties as well. Organotin compounds includes the following non-exhaustive list of compounds: tibutyltin (TBT), dioctyltin (DOT), dimethyltin (DMIT), dibutyltin (DBT), tetrabutyltin (TeBT) and others[243].

Hazard Profile

Many of the heavy metals used in carpets can be toxic to human and environmental health. Heavy metals are natural components and cannot be degraded or destroyed. As a result, heavy metals are dangerous as they tend to bioaccumulate in organisms and consequently up the food chain. Many heavy metals above certain exposure pathways and levels have known neurotoxic, carcinogenic, and developmental effects[244].

Lead is classified under CLP as being toxic to reproduction as well as have specific organ toxicity which may include brain and kidney effects. Children exposed to lead are associated with slow cognitive development and other effects[245], [246].

Cadmium and its compounds are known carcinogens, mutagens, and reproductive toxicants. Exposure may also result in kidney damage and may lead to bone loss[247].

Mercury and its compounds represent a large class of chemicals with varying hazard profiles[248]. However, mercury compounds in general are regarded as toxic and known to be reproductive toxicants. Mercury and its compounds are also known to exhibit toxic effects to the nervous, digestive, and immune system, as well as lungs, and kidneys.

Organotin compounds may act as immunotoxicants, impair human fertility and/or cause harm to unborn children[249]. Cadmium and its compounds are 'highly toxic and exposure to this metal is known to cause cancer and targets the body's cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems'. Silver may cause mild skin irritation but also has the ability to impact kidneys, eye, lungs, liver, and brain to overexposure[250]. Toxicity of nano-metals is still not well understood and currently being evaluated globally[251].

Regulatory and Certification Profile

The regulatory profiles of heavy metals are wide ranging. Many global standards exist that set heavy metal limits for children's products such as clothing as well as paints, electronics, and packaging – and do not always extend to their use in carpets. Below we explore some of the regulations that exist to reduce the use and exposure of heavy metals and their compounds in textiles.

Lead is restricted under REACH at concentrations greater or equal to 0.05% by weight in articles or accessible parts that may, under normal or reasonably foreseeable conditions of use, be placed in the mouth of children[245]. Other items that have been identified as falling within the scope of this restriction are accessories, clothes, buttons, interior decorations, etc. An article or accessible part is defined as being "smaller than 5 cm in one dimension or has a detachable or protruding part of that size". Carpets do not fall under this restriction.

Cadmium, is restricted both under the Toy Substance Directive (TSD) as well as REACH. Under the TSD, cadmium cannot be found in children's toys in amounts >0.01 %. Cadmium is currently restricted in plastic materials such as PVC (as well as recovered PVC), polyurethane, and PET in concentrations >0.01% by weight[252]. A recent REACH enforcement project found that about 5% of plastic materials for children's toys products were out of compliance with the current cadmium limit for children's products[253]. Although the report did not state, compliance issues may primarily arise from imports.

Among other restrictions on mercury, it is restricted in the EU “in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture”[254], but not currently restricted for its use as a catalyst in materials such polyurethane[255] and other materials. Specific compounds of cadmium and mercury[256] have been already been restricted in their use in textiles in the EU, however, these restrictions only apply to a small set of these compounds on the market that may are currently used in the dyeing or manufacture of carpets and likely doesn’t capture other toxic compounds.

Several organotin compounds such as tri-substituted organotin compounds, DBT compounds, and DOT compounds have been restricted in all articles, including carpets, at concentrations >0.1% by weight[257].

Currently there are no restrictions placed on silver. However, silver was added to community rolling action plan (CoRAP) in the Netherlands. As a result, ECHA requested more ecotoxicity information and reproductive toxicity testing in order to gain a better understanding of nano-silver, its uses, and potential environmental and human health impacts[250].

Recognizing the potential hazards associated with heavy metals and the risk they post to human and environmental health, specific eco-labelling schemes (i.e. GUT, Nordic Swan, and Oeko-Tex) use standards which ban or restrict the allowable limit of total and extractable heavy metals in carpets, giving clearer guidance that regulatory authorities do not currently offer with regards to heavy metals in carpet. Additionally, Blue Angel has banned the use of dyes containing heavy metals such as cadmium, mercury, lead or nickel.

Note: It is recognized that this is a non-exhaustive list of toxic heavy metal compounds and that other toxic heavy metals, such as antimony as used in PET, may also be found in the manufacture of carpet. It is also recognized the use of heavy metals is nearly impossible in most industrial applications (as they are necessary in the production of most plastic materials). However, we have seen the successful replacement of lead, mercury, cadmium and organotin compounds in many applications through the use of less toxic metals such as Zinc and/or through the use of new technologies. We continue to advocate for such alternatives for all toxic heavy metals that may find their way into carpet.

Exposure Profile

Workers

Worker exposure to heavy metals have a number of exposure pathways which include oral, dermal, and/or inhalation. For example, the U.S. estimated that approximately 300,000 workers are exposed to cadmium across multiple industries including the following[258]:

- Those involved in landfill operations
- Those involved in the manufacturing or recycling of plastics
- Waste collectors (as dust may contain cadmium)
- Those involved in the incineration of municipal waste

Despite the restriction of cadmium in plastics since 2011, it is likely that this substance and its respective compounds will remain in recycled materials.

Consumer

As carpet is used and abrasion occurs, heavy metals found in carpets materials will be released and can adhere to air particles such as dust and can be inhaled. Children are particularly vulnerable to heavy metals and their toxic effects. Textile effluent can discharge heavy metals into the surrounding waters even when treated properly. Many waste water municipal facilities do not have 100 % efficiency removal of heavy metals, meaning heavy metals get released back into the environment and impact surrounding communities

Disposal Profile

Landfill

Heavy metals accumulate heavily in landfill sludge and are non-biodegradable. Current treatment methods that exist for heavy metal removal are expensive and often inefficient for removal, which means they are then released back into the environment[259].

Incineration

Heavy metals can be a problem when they become of the fly ash that is sent to landfill, where it can pose an additional hazard. On top of this, some of these elements, particularly Pb and Hg, are highly volatile and may be released atmospherically if appropriate emissions controls are not present[260].

Recycling

Like most additives in recyclable materials, heavy metals can impact the recyclability of materials by increasing or decreasing thermal stability of plastic material making the end product variable in composition. Heavy elements can be difficult to remove from plastics, leading to further contamination of secondary materials.

Recommendations

Policymakers: Lead, cadmium, and mercury should be restricted under REACH for the use in carpet materials and dyes.

Manufacturers: Metals are necessary for many of the processes of carpet manufacture and therefore their use cannot be fully avoided. However, manufacturers of carpets and carpet materials should avoid the most toxic metals such as lead, cadmium, and mercury in all chemical auxiliaries and processes including dyes. For manufacturers of natural fibre carpets that typically use mordants, avoid the use of toxic heavy metals mordants such as chromium and replace with less toxic metals. This assumes that their use in this application has not already fallen under Restriction. Additionally, when using materials such as PU and PVC, organotin compounds should not be used and less toxic alternative catalysts in this materials should be used as replacements.

5.7 Dyes and Pigments

Chemical Profile

There are many chemical dyes and pigments used for carpets. There are a few different dyeing methods for carpets. Tufted carpets are either dyed after the carpet is tufted (post dyeing) and prior to tufting (pre-dyeing). Woven carpet is typically produced with pre-dyed yarns, however, some may be post-dyed via printing.

Post-dyeing involves various processes of dyeing yarn after being tufted and done by continuous dyeing, beck dyeing or printing. Continuous dyeing uses spray jets that continuously and evenly apply the dye across the carpet. Beck dyeing is essentially a dye bath where the carpets are immersed in dye contained in steel tanks. Print dyeing uses roll on or jet applicators similar to continuous dyeing and can obtain patterns[99].

Pre-dyeing involves various processes in which the yarn or fibre is dyed prior to tufting or being woven. The most common pre-dyeing method is solution dyeing, used only for synthetic fibres, in which the polymer used to make the carpet fibre is melted and the dyes are dispersed into the polymer to desired colour.

There are thousands of different dye and pigment substances used in the dyeing process for carpet. Of interest are azo dyes, which are the large class of industrial colorants used in the dyeing process for both natural and synthetic textiles[261]–[263]. Additionally, toxic heavy metal dyes are of concern in carpets as well.

Hazard Profile
Many azo dyes are relatively non-hazardous. However, a small group of known azo dyes break down into the more hazardous aromatic amines. The breakdown of the azo dyes into the more hazardous aromatic amines can occur either through what is known as reductive cleavage - such as the body coming into contact with sweat, or through the body's own enzyme system – such as being ingested and being broken down by the enzymes in the body.

However, the subset of azo dyes that break down into aromatic amines is concerning given their hazards. For example, aniline is an aromatic amine classified in the EU as a skin sensitizer, mutagen, and carcinogen.
The EU currently restricts azo dyes that can breakdown into one or more of 22 carcinogenic and/or mutagenic aromatic amines. A Swedish report for textiles identified several others aromatic amines which have similar characteristics stating, "There are a large number of azo dyes that have been identified for use in the textile industry. A compilation of known dyes (the Colour Index database) lists approx. 2,000 azo dyes. A scientific review has identified 896 azo dyes with a known chemical structure. Of these 896 azo dyes, 426 can be metabolised into one or more of the 22 regulated [aromatic amines], while the other 470 azo dyes can be metabolised into other [hazardous] aromatic amines which are not regulated at present"[264].

Even seemingly non-toxic dyestuff discharged into waterways from textile operation effluent can present a hazard as it decreases the availability of sunlight to enter the water creating a lack of oxygen and consequently negatively impacting aquatic biota[265].

Regulatory and Certification Profile
In the EU, azo dyes that break down into any of 22 specific aromatic amines are restricted under REACH above 30ppm in any textile which comes into contact with the skin. Azo dyes that may break down into aromatic amines resulting from residues of previously dyed fibres of recycled materials are restricted in concentrations above 70 ppm[266].

Additionally, the Swedish Chemicals Agency is looking to propose a restriction on additional hazardous aromatic amines, as well as any azo dyes that break down into these aromatic amines, identified to be carcinogenic and/or mutagenic identified in the Swedish report[264]. (Appendix I lists 12 of the azo dyes mentioned).

Blue Angel, GUT, and Oeko-Tex certification schemes do have lists of dyes and pigments they currently restrict from their certification – which includes the currently banned azo dyes as well as carcinogenic and allergenic dyes. In addition to the azo dyes and allergic dyes, Nordic Swan also bans all CMR substances as well as substances that may degrade into CMR substances. However, a complete investigation of the >10,000 dyestuffs, and consequently their hazards, available on the market is impossible.

Because anilines (aromatic amine used in PU and dyes/pigments) are hazardous and ubiquitous in our environment, they have been identified as one of several priority chemicals. The EU is currently conducting human biomonitoring studies on several priority chemicals – anilines being one class of chemicals – in order to enhance chemical safety and support policy making[267].

According to a report from ZDHC discussing wastewater quality guidelines for apparel textiles in Europe (which typically have stricter standards than other textile products such as carpet) states, "…Among the locations benchmarked for this effort, it was rare to find a regulation that published a comprehensive table summarising limit values that could be applied to industrial wastewater discharged to a water body. Regulations do exist that cover environmental protection but specific effluent limits are seldom listed. Discharge permits often are established based on circumstantial parameters such as the wastewater composition, location of the industrial facility, whether the effluent will be sent to a POTW or directly discharged to a water body and the type and quality of the receiving water"[268]. In other words – it is likely that stricter governance around textile effluent – is needed.

Exposure Profile

Workers

The majority of azo dyes are water soluble and make it easy for the body to absorb. Therefore, exposure to these compounds can occur 1) during manufacturing process of azo dyes 2) when the azo dye in carpet is exposed to sweat, thus triggering the break down into the more hazardous aromatic amines (where applicable) 3) during the manufacture of carpets once migrated and adhere to dust. Therefore, those involved in the manufacture of azo dyes, dyeing of carpets, production of carpets containing azo dyes, as well as workers handling carpets either during install or removal, are susceptible to increased exposure to these substances and consequently their hazards.

Consumers

Consumers may also trigger breakdown of azo dyes into aromatic amines with dermal contact. The research around brominated azo dyes being found in carpet also shows how these hazardous aromatic amines can migrate from the carpet fibres leaving children, with their hand and mouth behaviours, particularly vulnerable to their toxic effects. A recent REACH enforcement project found that about 1% textile clothing articles tested were out of compliance with the restriction on azo dyes which is expected to be higher in carpets since apparel and clothing are more strictly regulated[253].

Additionally, the dyeing process is a water intensive process in which waste water discharge is released in the water ecosystem, potentially finding their way into surface and ground waters. Azo dyes are difficult to breakdown for most treatments and often find their way into the environment. Because of this, surrounding communities may also be impacted by the effluent discharge[269].

Disposal Profile

Landfill

Biodegradation of azo dyes in landfill leachate is difficult because of their often complex structure and synthetic nature. Most treatment techniques have been explored for recalcitrant dye wastewater with no 'one-size fits all' solution[270]. However, their toxicity to the aquatic environment makes their discharge into the environment undesirable given their potential environmental hazards[271].

Incineration

The class of azo dyes is wide ranging and depending on their functional groups could have a number of potential thermal decomposition products[272]; under EU incineration guidelines, it would be expected that these substances would undergo complete degradation in MSW incinerators.

Recycling

Because azo dyes and other potentially harmful dyes directly adhere to the carpet fibres, their presence would likely be found in recycled material. Azo dyes may also impact recyclability of plastics because of the creation of undesirable colours in new products. While there are allowable limits for azo dyes that breakdown to the hazardous aromatic amines, there are still potentially hazardous CMR dyestuff that exists can be recycled back into the material but little else is known.

Recommendations

Policymakers: The enforcement of waste water discharge regulations should be prioritised across member states in the EU to ensure compliance. The current azo dye restriction should be expanded to include the aromatic amines mentioned in Appendix I of this report. REACH obligations should be expanded to all CMR aromatic amines as well as the azo dyes which are known to breakdown into these aromatic amines – and at minimum should include the 40 dyes found in recent research with the intention of banning all CMR substances. An alternative would be a specific carpet regulation equal to dye chemical restrictions in textile apparel.

Manufacturers: Dyes and pigments used in the textile industry are necessary. However, managing their toxicity and disposal must be adequately controlled to reduce exposure. Manufacturers must strive to eliminate the usage of toxic dyestuff and move towards less harmful dyes. This is likely to need an enhanced level of cooperation with their supply chains to identify the safest dyes.

5.8 Polycyclic Aromatic Hydrocarbons (PAHs)

Chemical Profile

PAHs are large class of naturally occurring substances found in coal, crude oil, and gasoline. PAHs are produced in incomplete combustion of organic matter such as wood, coal, or oil (including combustion of plastics). PAHs are found in consumer products, as unintentionally added constituents, consisting of rubber and flexible plastics such as PET, PP, SBR and PVC as well as bitumen. These plastics are used in the manufacture of carpet fibres and backing. Many PAHs are also used in the textile dyeing process and may be found as impurities in dyestuff – particularly with the use of carbon black[273], [274]. Additionally, PAHs may be formed by thermal decomposition of recycled materials during reprocessing[275].

Hazard Profile

The large class of PAHs means there are also many hazards. Many PAHs are known carcinogens in addition to having other hazards. For example, Benzo[a]pyrene is a well-known carcinogen, mutagen, and reprotoxicant (CMR) as well as persistent, bioaccumulative, and toxic (PBT), in addition to being a skin sensitizing substance[276]–[279].

Regulatory and Certification Profile

ECHA, as well as other global government agencies such as the US EPA, regulate concentrations of specific PAHs in air, water, and soil[280]–[282]. In the EU, eight PAHs have been restricted in rubber or plastic components that come into contact with skin or oral cavity under normal conditions of use at >1 ppm. Carpet falls within the >1 ppm restriction unless marketed towards children; since for toys and childcare articles, the PAH concentration limit is 0.5 ppm. Since it can be assumed that all carpets are used by children, the PAH restriction should likely reflect the 0.5 ppm in carpets. Some specific PAHs are regulated under REACH; Benzo[a]pyrene for example, was added to the Candidate list in 2016 with others, such as Benzo[a]anthracene, following suit for possible inclusion onto Annex XIV where they could be banned from commerce entirely[283].

Exposure Profile

Worker

Workers in industries or trades using coal or coal products – such as rubber and plastics. All people are exposed to PAHs. However, during the manufacturing of plastic carpet fibres and backing materials workers likely have the highest exposure. PAH exposure happens mostly as a release to air. Additionally, those working in incineration and that handling of the resulting fly ash are also at increased risk of exposure to PAHs and should take extra precautionary measures to ensure safety[111], [275].

Consumer
All of us are exposed to PAHs through diet, smoking, burning of coal or even wood, as well as exhaust from vehicles. However, in carpets consumers are exposed primarily via dermal contact. PAHs can also enter the body through the lungs via inhalation, usually of particulate dust arising from carpet abrasion[284].

Disposal Profile
Landfill
Because PAHs can be found in the textile dyeing process, they can also be found in textile dyeing sludge and are difficult to treat in the wastewater treatment process. This sludge is either landfilled or incinerated. PAHs are often persistent, bio-accumulative, and toxic in nature making landfilling sludge a terrestrial hazard.

Incineration
Research around the incineration of PAHs has indicated that they are precursors of dioxin-like substance during incineration. However, given EU incineration guidelines, most toxic emissions will be captured and result in tolerable emissions or end up in fly ash.

Recycling
One of the big issues governing PAHs is their ability to form during thermal decomposition of recycled materials during reprocessing. That means when carpets or other plastic materials are recycled in order to create new carpet fibres, the concentration of PAHs increases.

Recommendations
Policymakers Since it can be assumed that carpet will be used by children, the REACH restriction on PAHs should reflect the concentration limit of 0.5 ppm per the Toy Substance Directive. The concentration of 0.5 ppm should also be reflected in recycled materials as well.
Manufacturers: Manufacturers should advise material suppliers to adjust time and temperature used to process plastic/rubber materials to reduce risk of PAH formation. This may be more difficult for recycled plastics owing to their variable composition. However, manufacturers should ensure these recycled materials are meeting PAH limits either by providing appropriate analytical testing and/or third-party certification.

5.9 Other VOCs – "New Carpet Smell"

Chemical Profile
Volatile Organic Compounds (VOCs) are organic compounds that easily become vapours or gases at room temperature. Many buyers covet the smell of a new car or new carpeting in their homes. However, that smell is the off-gassing of potentially toxic VOCs impacting indoor air quality and consequently human health.

Many of the chemicals used in carpets, some mentioned in this report, are toxic VOCs. For example, a survey and risk assessment of chemical substances in rugs for children identified that carpets are a possible source of exposure to styrene (as used in SBR latex carpet backings). The same survey identified that 4-phenylcyclohexene (4-PCH), which is a toxic byproduct from the polymerization of styrene and butadiene for SBR latex carpet backings, will be emitted for over 14 days at a high emission rate[285].

In addition to these VOCs, chemicals that may be present in newly installed carpet adhesives may include toluene, xylenes, 1,2-dichloroethane, 1,1,1-trichloroethane, as well as ethylbenzene.

Hazard Profile
The health effects of volatile organic compounds depend on the nature of the volatile organic compound, the level of exposure, and the length of exposure. Some VOCs are non-hazardous, while others may be carcinogenic, mutagenic, and reproductive toxicants. Styrene, for example, is suspected of being toxic to reproduction.

Regulatory and Certification Profile
The EU has VOC Solvent Emission Directives as the main policy for industrial emissions[286]. Additionally, some member states have VOC regulations such as Belgian VOC regulation, French VOC regulations, German VOC regulations, as well as the Finnish M1 voluntary emission standards of building materials[287].

However, most carpet manufacturers in Europe adhere to the GUT emission test which sets limits for total VOC content as well sets limits for specific substances such as styrene[288]. Certifications such as Nordic Swan, Oeko-Tex and Blue Angel have set permissible limits for emissions of total VOCs[106]. Oeko-Tex has a limit set at 500 $\mu g/m^3$, Nordic Swan has a set a total VOC limit of less than 300 $\mu g/m^3$, while GUT and Blue Angel have a more conservative total VOC limit at 100 $\mu g/m^3$.

Exposure Profile
Worker
Those working in the manufacture of the carpets are particularly susceptible to toxic VOCs in carpets. In order to meet strict VOC emission standard for certain certification labels such as Blue Angel, Oeko-Tex, and GUT, many manufacturers have to off-gas their carpets before sending to the labs to be tested for acceptable limits. This could potentially leave workers in charge of manufacturing, storing, and transporting these carpets particularly susceptible to the VOCs in these carpets. This doesn't necessarily mean that the carpet will not continue to off-gas, and therefore, installers are also susceptible – particularly if VOC guidance doesn't exist.

Consumer
The largest release of VOCs from new carpeting occurs within the first 72 hours after installation and continues to off-gas at a slower rate for years to come. Adhesives used to bind carpet material, carpet materials, as well as carpet padding all contain VOCs likely to impact indoor air quality.

Recommendations
Manufacturers: While the complete avoidance of VOCs is unlikely, it is recommended industry adopt the strictest total VOC standard of 100 µg/m3 and continue the phase out of hazardous VOCs.

5.10 Polyvinyl Chloride (PVC)

Chemical Profile
Polyvinyl chloride (PVC), commonly known as 'vinyl' in Europe, is one of the most commonly used thermoplastic polymers. PVC is used extensively as a carpet tile backing in the US and Asia (bitumen is the favoured backing material in Europe, but some PVC-backed tiles are sold there), and it is also used as a backing material for broadloom carpets, as well as a face yarn for a small number of products. Vinyl chloride monomer (VCM) is the building block of PVC and is derived from the raw materials ethylene and chlorine. However, many substances typically make up PVC that is found in carpets including phthalates, flame retardants, and many heavy metals used as heat stabilizers such tin (Sn), cadmium (Cd), and zinc (Zn).

Hazard Profile
Already mentioned in previous sections, but many of the hazards associated with PVC have to do with the 1) hazardous chemicals in the process of making PVC as well as 2) hazardous chemicals contained within the PVC and

migrate out. In addition to those chemicals and their hazards already mentioned in this report, the vinyl chloride monomer that is the backbone of PVC is hazardous and classified as a carcinogen in the EU. It is also expected to cause acute central nervous system effects, as well as chronic health effects such as liver, brain, lung, lymphatic and blood cancers as well as neurological diseases such as motor neurone disease. Residual amounts of the monomer can exist post production and can be inhaled[113].

As previously mentioned in this report, the heavy metals such as organotin compounds and cadmium are used as heat stabilizers in PVC flooring. The hazard profiles of these substances are substantially toxic, contributing to the overall negative hazard profile of PVC. (See section on heavy metals)

Outside the chemicals found within PVC, the manufacture of PVC is also one of the world's biggest users of mercury. The technology supporting the use of mercury is the chlor-alkali industry which committed back in 2001 to phase out all mercury operation by 2020. As of the end of 2016 the amount of mercury used by the chlor-alkali industry for the production of PVC was reduced to about 5400 tons in the EU[289]. Despite the decrease in the EU, the use of mercury in PVC operations still occurs globally, and needs to be considered when importing PVC products from China, since China accounts for the majority of chlor-alkali monomer used to produce PVC.

Regulatory and Certification Profile

As we have seen throughout this report, many of the chemicals that go into to the PVC process are being restricted. Despite the restriction of toxic chemicals, they are often replaced with 1) equally toxic substances that have not yet been restricted or 2) with less understood hazard profiles.

The manufacturing of PVC is also one of the largest users of mercury. Many companies have committed to new processes that remove the use of mercury in the production of PVC by 2020. Heavy metals, such as cadmium, are used as stabilizers in PVC. Although cadmium has now been restricted significantly across the EU as a use in plastics such as PVC, it may still be replaced with other toxic heavy metals[290]. However, less toxic alternatives such as barium and zinc do exist, although because manufacturers are reluctant to share the substances used in their processes as well as their effectiveness and usefulness in PVC application is not well known.

Because of the hazards associated with PVC, some EU member states have increased tax for products containing PVC in order to reduce phthalate use as well as to reduce PVC in landfill and incineration operations. However, in November 2017 Denmark announced it is now lifting their tax on PVC containing products because the Danish government says the tax "is no longer considered to have any 'significant behavioural effect on health or the environment' and so will end 1 January 2019." The lifting of this tax makes more environmentally friendly product less competitive and encourages the use of PVC and consequently the use and circulation of toxic substances[291].

Exposure Profile

Workers

For those working with or processing PVC or PVC containing products such as carpets, occupational exposure can occur during products use, transport, disposal of these products. Residual PV monomer and other chemicals in the PVC carpet can off-gas post-manufacture (or after any reprocessing including recycling).

Industrial facilities using PVC and its additive chemicals may have safety requirements, such as proper ventilation, and handling procedures in their operations. However, these safety and handling procedures don't always carry over to those handling the end finished product – including carpets and carpet installers who often do not wear protective equipment such as gloves and masks, leaving them particularly vulnerable to the off-gassing of chemicals in PVC carpet materials.

As previously mentioned, one example of chemicals migrating of carpets are phthalates. Approximately 90% of total phthalate production goes into PVC. Phthalates are not chemically bonded to the plastic but are mixed with the polymer during formulation. They therefore migrate out of the plastic over time into air, water, or other substances with which vinyl comes in contact.

Consumers
Vinyl chloride and other chemical additives in the PVC carpet materials, such as carpet backing, off-gas into household air. After carpet installation, the off-gas is highest during the first 72 hours, but can continue for years to come during normal use.

Environment
PVC cannot break down in the environment. Many of its environmental impacts occur during the manufacturing, processing, and disposal scenarios associated with its life cycle which include the migration and leaching of the hazardous additives out into the environment.

Disposal Profile
Landfill
PVC is known for its stability. However, many of the chemical additives that are in PVC can migrate out of the plastic into the leachate. Phthalates for example, are often semi-volatile and can migrate out of the plastics and released to air/dust. Chemicals like flame retardants may be difficult to manage in leachate[157].

Incineration
PVC incineration is a contentious issue as it can lead to dioxin (PCDD/PCDF) formation on burning.[14] While industry maintains that current incineration standards (both for MSWI and cement kilns) are adequate in limiting its release[115], many maintain that the health hazard posed by dioxins and their persistence, the other toxic substances in PVC, and the material's disposal cost far outweigh its in-use benefits[113].

Recycling
Recycling PVC is possible, but the wide range of chemical additives make it difficult to have a consistent end product; for example, rigid and flexible PVC need to be processed separately. As we've seen, these additives are often hazardous and will likely compound in recycled products. Additionally, PVC can be highly disruptive to recycling of other plastics, as low level contamination with PVC can render recyclate batches (e.g. for PET) unusable. [96] Additionally, PVC is inherently harmful and should be avoided as a material in carpet.

Recommendations
Policymakers: Products containing PVC should be discouraged through whatever means is most appropriate to the market, noting that tax at high rates has been used in some member states to continue to encourage greener chemistries and products to be created. Policy should not allow PVC containing articles to be sent to landfill and should require PVC containing carpets to be labelled as such.
Manufacturers: Manufacturers should move away from PVC as a material used in carpet backings (consequently decreasing the use of phthalates, heavy metals, and many other additives). Manufacturers using recovered PVC should test to ensure toxic additives are not recycled back into carpets. Manufacturers of carpets containing recovered PVC should be labelled as containing 'recovered PVC'.

[14] The WHO notes that high temperatures of over 850 °C (and over 1000 °C for contaminated materials) are required for complete destruction. [255]

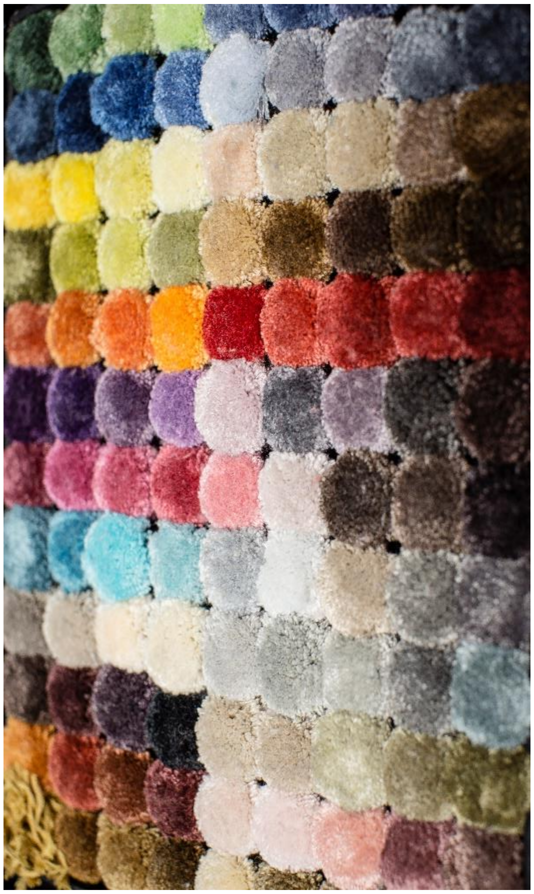



Photo Credits: Will Rose

5.11 Styrene Butadiene Rubber Latex (SBR Latex)

Chemical Profile

Styrene butadiene (SB or SBR) latex is the most commonly used polymer derived from the polymerization of the monomers styrene and butadiene. SB latex is the most common polymer used to bind layers in carpets, often fusing the face yarn to backing.

Hazard Profile

SB latex is very similar to PVC in that it is generally thought to be an inert material, however, many of the hazards that exist with SB latex have to do with the 1) hazardous chemicals in the process of making SB latex as well as 2) hazardous chemicals contained within the SB latex backing and migrating out.

In particular, the styrene and butadiene raw materials used to create the SB latex polymer are particularly hazardous. Under REACH styrene is classified as a reproductive hazard. Butadiene is classification as a carcinogen and mutagen. Specific cancers include leukaemia and lymphoma. Both of these chemicals are particularly volatile.

Styrene and butadiene that are not polymerized may create 4-phenylcyclohezene (4-PCH). 4-PHC is a semi-volatile compound and a suspected carcinogen generally found in SB latex. 4-PCH has historically been known as the chemical creating the 'new carpet smell' as it has a strong odour even in small amounts. It has been studied that 4-PCH may also react with ozone to create formaldehyde.

Some of the constituents that go into make styrene are not well known seeing as manufacturers do not release the components of their 'recipes'. Some of these additives substances include flame retardants, curing agents, foaming agents, and others.

Regulatory Profile

Styrene monomer and 1,3-butadiene are two of many large volume chemicals subject to periodic risk assessment review in the EU.

1,3-Butadiene was recently added to the Carcinogens and Mutagens Directive in order for government to establish nation-wide occupational exposure limits (OELs) for a number of carcinogenic and mutagenic substance in order to protect workers from these hazardous substances. Many member states have already established their own OELs for specific substances, however, these can vary considerably from member to state to another. An EU-wide OEL value would ensure the highest level of work safety across the EU[292].

Styrene has occupational exposure limits (OELs) established by various member states that range from 20 ppm in Germany, Austria, Finland, Italy, Spain to 100 ppm in the UK.

GUT sets a VOC limit for 4-PCH at <2000 mg/m3. The Blue Angel sets a limit for 4-PCH at <5000 mg/m3. Oeko-Tex has a 4-PCH VOC limit of <30 mg/m3 (although Oeko-Tex does not monitor SB latex backing, only face fibres). These variable limits suggest there is not a clear picture on what 'safe' is for workers and consumers regarding these substances.

Exposure Profiles

Worker

Residual styrene and butadiene are released in the manufacture of SB latex. Workers may also be exposed to the dust and vapours released from the additive chemicals as part of the SB latex formulations as well – further exposing other workers exposed to SB latex in the life cycle of the carpet.

Consumer

Consumer exposure to these chemicals typically occurs when residual monomers remain in polymers. Depending on the additives, such as flame retardants, used in these chemicals, consumers may be exposed as well.

Disposal Profile

Landfill

SBR may leach contaminants when landfilled. Post-consumer tyre crumb (tyre granules) has been found to absorb heavy metals, VOCs, and provide a substrate for microbial activity.

Incineration

Incineration of SBR products such as tyres is common in Europe due to their high calorific value and little other use at end-of-life. While complete thermal decomposition of the material should occur at mandated operating temperatures, SBR has a tendency to generate PAHs, particularly in low-oxygen environments[111]. Combined with chlorine substances potentially found in carpets, this may promote formation of dioxins.

Recycling

There is little evidence that the SBR elements of carpet are recycled, however may be reduced to a granular form and then reprocessed and although they may find application in materials for carpet backings, floor mats, and shoe soles.

Recommendations

Manufacturers: While these polymers are not hazardous in their own right, they are difficult to recycle and also have the potential to harbour a number of the additives that have occurred earlier on this list. The eradication of these additives does not require the avoidance of SBR and Polyurethane, users of these matrices need to be doubly sensitive to their potential to contain such hazardous chemicals and satisfy themselves that they do not.

5.12 Polyurethane

Chemical Profile

Polyurethane (PU) is a polymer derived from the reaction of isocyanates with polyols. PU is used in carpet backing and PU foam is used as carpet padding[293]. The two most common isocyanates used in the production of PU are MDI and TDI. These isocyanates can also degrade into anilines (aromatic amines)[294]. In addition to be formed as a degradation product, anilines are also used as intermediates in the manufacture of PU.

Hazard Profile

Polyurethane as a polymer does not present any known hazards. However, the various chemicals that are used in the production of polyurethane, such as the aforementioned isocyanates and anilines, are hazardous.

Diisocyanates, methylene diphenyl diisocyanate (MDI) and toluene diphenyl diisocyanate (TDI) for example, are known skin and respiratory sensitizers as well as suspected carcinogens. Additionally, diisocyanates are a major cause of occupational asthma[295]. Free, unreacted isocyanates are commonly present in polyurethane consumer products. They have been identified on the surface of polyurethane carpet pad and pillows, for example[296].

Anilines are aromatic amines and are suspected carcinogens and have concerns related to genotoxicity. Anilines are easily absorbed via inhalation or skin contact and are known to interfere with the body's ability to carry oxygen in the blood[297].

PU is also known for the use of brominated and other hazardous flame retardants[205]. For the flexible PU products, the flame retardants are typically additive meaning they can migrate more easily from the carpet padding leaving users exposed.

Regulatory and Certification Profile

As of December 2010 MDI is restricted in the EU in concentrations >0.1% by weight to the general public unless suppliers ensure certain PPE and disclosure is met before the placing on the market[298]. The regulation therefore doesn't restrict the use of MDI but rather place stricter supplier packaging requirements. This restriction on packaging requirements does not extend to the other diisocyanates.

As of December 2017 MDI *and all other diisocyanates* are restricted by ensuring mandatory workplace training in order to prevent new cases of occupational asthma from exposure to diisocyanates[299], [300]. There is no current restriction on the use or acceptable thresholds on isocyanates in articles - such as those that would be found in polyurethane carpet backing.

Many anilines are on the candidate list in the EU and will eventually be banned from commerce unless an Authorisation has been granted. Therefore, the use of anilines as intermediates in PU may mean a ban from commerce. However, anilines are degradation products of MDI – which makes them unintentionally added substances[15]or by-products and typically don't fall under such regulations.

Exposure Profile

Worker

MDI has the highest volume in the manufacture of PU and PU materials. Unreacted isocyanates are released into the air through workplace activities such as heating PU plastics as well as cutting PU foams. Many reports of workplace respiratory sensitization resulting from isocyanate workplace exposure have been reported resulting in the aforementioned restriction. As stated above, isocyanates have been reported to be found in PU foams likely making carpet padding manufacturers, installers, and removers particularly exposed and susceptible to the toxic effects of isocyanates.

Consumer

Research and data is limited in consumer exposure to isocyanates in PU foam. However, while workers have the greatest exposure to diisocyanates, consumers could still become exposed as carpet padding wears away over the years, thereby creating PU dust and releasing these compounds. Yet carpet consumers containing these compounds receive not information on these chemicals and how to keep themselves safe despite potential exposure.

Disposal Profile

Landfill

If polyurethane foams can no longer be downcycled, they typically end up in landfill. Polyurethane, as will many plastics, is near impossible to degrade and little information exists on its behaviour in landfills. Isocyanates may

[15] Unintentionally added substances are chemicals present in a products but have not been intentionally added for a technical reason during production/manufacturing of the product. Because the legislation only controls the intentional use of chemicals.

leach out of polyurethane wastes.-However, isocyanates are highly reactive with water. This reaction creates solid polyureas that Dow Chemical calls “chemically and biologically inert.[301]” However, laboratory testing of polyureas formed from the reaction of isocyanate reacted with water and scrap found traces of free isocyanates 28 days after the reaction began[301]. Even a drop of isocyanate can cause the onset of respiratory diseases, as Dow acknowledged in an internal document[302].

Other additives, such as flame retardants, also leach out of polyurethane wastes, and have been identified in water around landfills[303].

Incineration
On combustion, PU is known to emit various isocyanate compounds; under incineration conditions these are likely to decompose further to hydrogen cyanide, ammonia, and other nitrogen compounds which need to be effectively scrubbed from emissions[128], [129]. Combustion of halogenated flame retardants in polyurethane foam creates dibenzo-p-dioxin and dibenzofurans[303].

Recycling
Polyurethane is different than most other thermoplastics in that it can’t be remelted. However, PU can be downcycled as bonded foam, where various polyurethane foams are bonded together to create a new product, usually with adhesives containing isocyanates [293].

Recommendations
Manufacturers: Polyurethane should be avoided for use in carpet backing materials. Additionally, avoid the use of recycled and bonded polyurethane foam for the use carpet padding as these contains high amounts of unnecessary flame retardants. U.S. EPA’s Design for the Environment has issued an alternative assessment update on PUR flame retardants: ‘Flame Retardants Use in Flexible Polyurethane Foam: An Alternatives Assessment Update’.

5.13 Exposure Pathway Summary

Workers Exposed to Toxic Chemicals Involved in Industrial Manufacturing Processes for Carpets
Product and chemical manufacturer workers are not fully protected from the hazards associated with the variety of chemicals used in the workplace. Cancer is the first cause of work-related deaths in the EU, accounting for 53% of total and therefore the single biggest health risk to workers in the EU. Exposure to chemical agents can result in cancer and ‘it is clear that many work-related cancers can be prevented by reducing or eliminating the exposures [to chemicals] leading to the disease’[305], [306]. In summary, hazardous substances are not safe and a better understanding of workplace exposures to hazardous substances and risk reduction strategies – which may include the complete removal of the substance – need be better understood.

Workers are currently protected under EU legislation under the Occupational Safety and Health (OSH) Framework Directive (89/291/EEC)[307]. The directives under the OSH framework dealing with chemicals include the ‘Chemical Agents Directive’ [308] as well as the Carcinogen and Mutagens Directive (2004/37/EC)’[309].

In July 2017, The European commission signed an agreement amending the Carcinogens and Mutagens Directive in order to protect workers better against several cancer-causing chemicals[305], [306]. Specifically, the proposal is to provide industry with Occupational Exposure Limits (OELs) not yet set for a subset of 20 carcinogens. Chemicals in this report on the proposed list include MDA, PAH mixtures, 1,3-butadiene, vinyl chloride and chromium. While this amendment is an important step in the right direction, it does draw attention to the fact that still more work remains to deriving OELs for other toxic substances in the workplace, particularly those working in the plastics and recycling industry as many may be exposed to fugitive dust and vapours.

As we have seen in many of the chemical specific profiles, many chemicals are used in the manufacturing process of carpets, particularly in the production of the carpet materials, pre-treatment of fibres, dyeing, washing and finishing – leaving carpet manufacturer workers particularly vulnerable to their toxic effects in the process. Not all facilities implement the same level of safety. While the OSH lays out a framework for facilities, that does not mean these process and safety measures are always implemented. There are often gaps in regulations and ensuring worker safety, as we have seen in the development of OELs.

Carpet Installers Exposed to Toxic Chemicals

While manufacturing has some guidance, carpet installation has little safety measures in place. The most toxic time to be around a carpet is within the first 72 hours after installed. This is when the VOCs from the materials are released – many of which are carcinogens, mutagens, and reproductive toxicants. If we think of carpet installers, they are one of the, if not the, most highly exposed population to the hazardous chemicals found in carpets.

If carpet installers were provided guidance similar to what manufacturing workers are, they would be required to wear appropriate PPE, such as gloves, skin contact protection, as well as respirable requirement[310]. Carpet installers generally do not wear this kind of PPE. If we consider the effects of many of the chemicals used in carpets – skin and respiratory sensitizers, carcinogens, mutagens, reproductive hazards, and endocrine disruptors we would want to consider many protective measures for the carpet installer who is in direct contact with the carpets via dermal and inhalation contact.

Environmental Exposure to Toxic Chemicals in Carpet Manufacture Effluent

We know that negative environmental health impacts correlate to negative human health impacts. Therefore, it is important to know which chemicals are hazardous in carpets and find their way into the aquatic environment and potentially into soil and air.

The manufacture of carpet is a very water intensive process. There are many processes in the carpet manufacture in which toxics from carpet can make their way into waterways. The manufacture of carpets requires many wet processes and thus these get discharged. Therefore, toxic effluent may enter the waterways either 1) by direct discharge (although unlikely given strict regulation) 2) partial on-site treatment 3) municipal waste water treatment 4) incineration (sludge). Partial on-site treatment and municipal waste water treatment often do not have 100% removal of recalcitrant chemicals and therefore, these chemicals may enter waterway and continue to persist post-treatment.

Substances that are persistent, bioaccumulative, and toxic will continue to impart their toxic effects in the aquatic biota for years to come. Even seemingly insignificant amounts of these substances released over time can create huge problems years down the future, such as what we are seeing with PBDEs and PFOSs. However, even non-hazardous effluent can be of concern of waters if not handled properly by reducing the waters oxygen content and consequently impacting the aquatic biota.

Exposure to Toxic Chemicals in Carpet Incineration

While the EU does have many regulations governing emissions from the incineration of products, the system does not mean zero emissions. The Waste Incineration Directive 2000/76/EC is in place to reduce negative effects caused by incineration or co-incineration of waste by reducing emissions into air, soil, surface and ground water, and consequently reduce potential human health effects[89], [90]. However, it has been questioned how well these incinerator plants are designed, operated, monitored, and how well regulations are enforced[311].

Regarding emissions, the directive sets emission limit values and monitoring requirements for pollutants to air such allowing certain competent authorities flexibility to set less strict emission limit values. Most incinerated waste produces many of the same stable end product such as carbon dioxide (CO_2), water (H_2O), sulphur oxides (SO_x), but may release toxic emissions such as dioxins and heavy metals. At best, these toxic emissions may be captured in the air pollution control device as toxic fly ash[311]. This fly ash must be further disposed of, falsifying the assumption that 'waste-to-energy' isn't actually wasting.

Sweden, touted it for its efforts in reducing waste-to-landfill, came under fire in 2015 when a report brought attention to their dumping of 500,000 tonnes of toxic fly ash on the island of Langoya, Norway at a landfill[171], [312]. The residual fly ash contains toxic pollutants, including heavy metals, PAHs, dioxans, and furans. These chemicals end up in landfill leachate/sludge and, although unlikely in properly managed landfills, have the potential to migrate into the surrounding soil and waterways[313].

Exposure to Toxic Chemicals in Recycling Processes

Preparation of carpet for recycling often generates a lot of dust, particularly when separating backing from the yarn. Some systems use suction to capture the face fibres; however, many recycling operations feature more rudimentary shredding equipment, particularly in the case of downcycling. There is a significant risk of dust inhalation by workers, particularly if PPE guidelines are not followed; in any case, it is possible for fibre to stick to clothes or skin, leading to inhalation or ingestion later on. Downcycled material is likely to contain many residual toxic substances (dyes, surface treatments) which can then be released to the environment during their second life.

Additionally, the recycling of plastics often requires the heating of these plastics; consequently, this can release any of the aforementioned hazardous thermal degradation products. If proper industrial hygiene practices do not exist to ensure workers are properly protected, such as personal protective equipment, adequate ventilation, and established OELs, recycling workers can be exposed to their toxic effects. As previously mentioned under the Carcinogen and Mutagen directive, harmonised OELs do not exist across Member States alluding to that fact safe limits may not yet be well understood and that the continual removal of hazardous substances from products and supply chains is necessary

Consumer Exposure to Toxic Chemicals in Carpet Use

Consumer exposure to substances in carpets occurs across multiple pathways – including ingestion, inhalation, as well as skin/eye contact. As the report has stated, many toxic chemicals in carpets tend to migrate from carpet fibres and impact indoor air quality. "New carpet smell" is really the off-gassing of toxic chemicals making their way into the indoor air and consequently into the lungs of adults and small children. Additionally, the normal use and abrasion of carpet may also expose toxic chemicals. These substances may be inhaled, or adhere to dust where they may also be inhaled as well as ingested. As mentioned throughout the report, children are particularly susceptible to their toxic effects.

All things are essentially made of chemicals - and that includes carpets. However, not all things need to be made from toxic chemicals. Consumers generally assume the products they are purchasing, and consequently the chemicals contained within, have to be safe in order to be sold. As we have seen, only minimum regulatory requirements are currently in place governing chemicals in carpets. While the REACH legislation does address chemicals in articles to some extent - gaps exist within this framework. For carpets in particular – the lack of chemical transparency across the carpets life cycle and questionable enforcement on ensuring imported carpets are adhering to the same level of safety as those produced in the EU appears to be a real concern for consumers. The lack of proper transparency and enforcement will continue to enable hazardous chemicals on the market and may facilitate their continued use in recycled products.

Cumulative Exposure – "The cocktail effect"
"The cocktail effect is the combined effect when you add up your exposure to many different substances from many different products. Even if the single product is safe, your combined exposure can be too high[314]." Over the lifetime of a carpet, exposure to toxic substances can take place via inhalation, ingestion, and dermal contact as phthalates, flame retardants, and PFASs make their way into the air, dust, and environment.

Research currently hasn't grasped a full understanding on how cumulative exposure to various chemicals impacts our biochemical pathways. The current way of assessing hazards and risks are typically on the evaluation of single substances. Furthermore, it is known that some chemicals may be released, mixed and more toxic when combined. However, little research exists to understand cumulative exposure and the combined effects of multiple chemicals[315]. Which is why we must presently take a precautionary approach to chemical risk by reducing the amount of hazardous chemicals circulating in products as possible.

Risk = Hazard x Exposure
There are really only two ways to reduce the risks associated with chemicals: 1) Reduce hazards 2) Reduce exposure. We have shown in this report that despite often having proper procedures in place, or at least best available standard operating procedures, the leading cause of work-related death is cancer with a large portion of that due to occupational exposure to chemicals. This is a good indication that industry is not doing a good job at controlling exposure and a more reasonable approach is the reduction and/or elimination of toxic substances which can be created through better carpet designs, better technologies, and better chemistries to ensure the human and environmental health and safety.

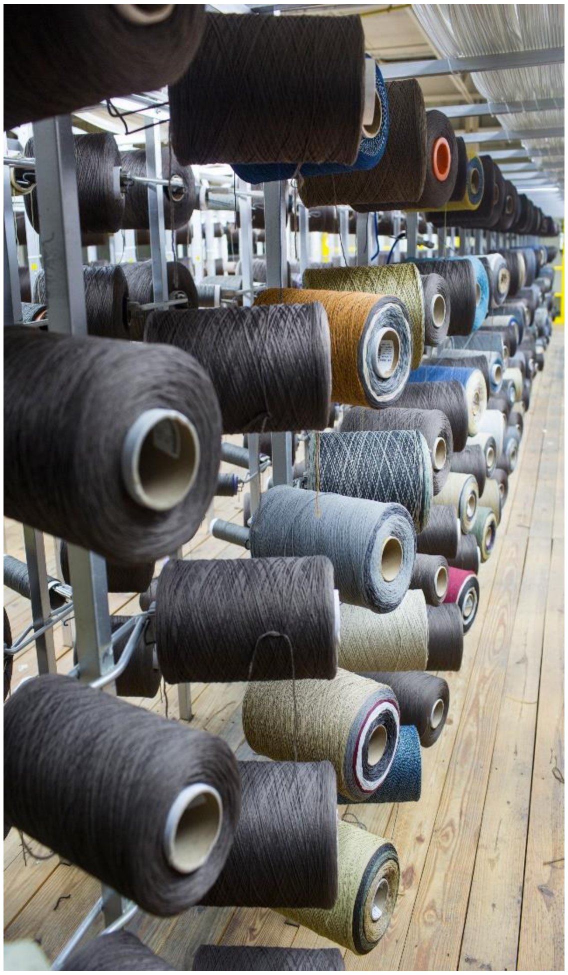


Photo Credits: Les Stone

6 Impacts & Cleaning Up

6.1 Material Impact

Owing to large range of materials, chemicals, manufacturing processes etc., as well as a reluctance from manufacturers to fully disclose the substances used in products, it is difficult to quantify the potential impact of toxic substances in the EU market without a robust evidence base of sampling studies.

A study by a group at the Fraunhofer Institute in Germany sampled several carpets during 2010, finding that all samples contained at least one PFAS: in many cases, the levels present exceeded the regulatory thresholds of the time (1 μg/m^2)[221]. For antimicrobial treatments, loading will depend on the substance used, but in many cases this will exceed 1 g/kg [176] — assuming that 50 % of carpets placed on market contain this level of treatment, almost 900 tonnes of antimicrobial treatments will be present in the stock of carpets placed on market in a year, much of which will eventually be released to the environment through multiple pathways.

6.1.1 Impacts during Recycling

Treatment of post-consumer carpet is heavily reliant on shredding, both in recycling and often prior to incineration. There is wide variation in the complexity of equipment used to disassemble carpet, ranging from bulk shredders to machines which effectively separate backing from yarn and use suction to reclaim the face material. Shredding produces significant amounts of small particulates which can pose a hazard to workers, particularly if PPE guidelines are not stringently followed. Additionally, particulates can persist on skin or clothing, potentially leading to inhalation or ingestion. Furthermore, depending on the layout of facilities, this may also lead to release of dust into the surrounding environment.

6.1.2 Impacts from Applications of Downcycled Yarn

Mechanically downcycled post-consumer yarn is often used in felts, insulation, and commonly for equestrian surfaces, with some 18 % by weight of the carpet waste handled by Carpet Recycling UK being used for equestrian applications, amounting to ~25 kt of material – this is subsequently mixed with shredded tyre waste and sand[316]. Equestrian surfacing is used outdoors, and therefore provides a direct route into the environment for substances of concern, particularly for PFASs and biocidal substances which are typically applied to carpet in relatively high concentrations as topical treatments. Felts are also used in horticultural applications, which would provide a similar route for substances to enter the surrounding environment[317], [318].

6.2 Certifications

The following is a list of identified certifications currently in place in Europe that govern specific attributes of the carpet. While some are multi-attribute certifications, the focus here is on their ability to identify, limit or prevent the use of certain toxic chemicals in order to promote a less hazardous circular economy. In general, the ultimate goal of these certifications is to encourage innovation and the design of products that effectively and positively impact people and the environment.

While some of these substances have been restricted or are subject to phase-out under REACH or some other directive, many of these substances have no restriction or ban placed on their use in textiles. Certifications schemes assist in addressing some of the regulatory gaps. Appendix II identifies a list of hazardous substances that have been identified to be potentially contained as constituents of carpets and identifies where these certifications schemes overlap as well diverge on their restriction or allowed use of these toxic chemicals.

Additionally, while these certification systems go beyond regulation in many cases, they may in fact mislead consumers. As previously mentioned, consumers often believe that the products they purchase, particularly ones that are certified, have no hazards associated with them – and at the very least have ensured the highest level of safety possible. This section analyses different certification schemes and analyzes what chemicals are covered by them and how more can be done to broaden their scope, align industry, and provide increased human and environmental safety by further removing the identified chemicals in this report if not already applicable.

GUT (Gemeinschaft umweltfreundlicher Teppichboden)[319]**:**
is the only certification meant solely for carpets. GUT was founded by leading European carpet manufacturers in 1990. The aim is to 'improve continuously all environmental and consumer protection aspects through the life cycle of textile flooring'. The GUT label has identified a list of 'pollutants' (toxic substances) and has set a ban or a limit on each for their use in carpets.

Appendix II shows that only 13 out of the 59 chemicals identified in this report are banned or limited by the GUT scheme.

Oeko-Tex Standard 100[106]: is an independent testing and certification system for textile products. The certification has a list of chemical substances that are to be restricted or banned in the testing of the textile fibres. As far as carpet materials, Oeko-Tex only certifies the carpet fibres and does not certify other carpet materials such as PVC and SBR backing. Oeko-Tex sets limits on hazardous chemicals based on how likely the product is to come into contact with human skin. Clothing is product class I and received the strictest chemical limit requirements while carpet would be in the last class, Class IV, and consequently may have reduced requirements in order to meet the standard.

Appendix II shows that 32 out of the 59 chemicals identified in this report are banned or limited by Oeko-Tex Standard 100.

Blue Angel (RAL-UZ 154)[320]: is an internationally used eco-label administered by the federal government in Germany with the aim 'to provide reliable guidance for sustainable textiles based on environmental and consumer safety'. This certification covers materials and substances used during the manufacture as well as the use and disposal.

Appendix II shows that 51 out of the 59 chemicals identified in this report are banned or limited, making it the strictest. This largely has to do with ban on: halogenated organic compounds, flame retardants, phthalates, as well as SVHCs, CLP category 1A/1B carcinogens, category 1 specific target organ toxicants, and acutely toxic substances.

Nordic Swan (for floor coverings)[146]: is a voluntary ecolabeling system that looks at floor coverings materials, substances within, as well as the management of these chemicals across the floor coverings life cycle (including manufacturing, use and disposal). The Nordic Swan was introduced in 1989 by the Nordic Council of Ministers and managed by the non-profit, Nordic Ecolabelling Board. The Nordic Swan applies to Scandinavian countries, which includes Sweden, Denmark, Norway, Finland and Iceland. In addition to the chemicals outlined in Appendix II of this report, Nordic Swan bans the use of PVC in floor coverings.

Appendix II shows that 49 out of the 59 chemicals identified in this report are banned or limited. This makes Nordic Swan the second strictest certification. This largely has to do with its ban on: SVHCs, CMRs (Class 1A/1B), PBTs, vPvB, and endocrine disruptors, nonylphenol ethoxylates, phthalates, biocides, and flame retardants.

Cradle-2-Cradle Certified[321]: The Cradle to Cradle Certified Products Standard is a multi-attribute, continuous improvement methodology that evaluates products, systems and operations in order to improve human and environmental health. This certification is accepted and acknowledged globally and administered by the NGO Cradle to Cradle Products Innovation Institute. Product certification is awarded at five levels (Basic, Bronze, Silver, Gold, and Platinum). The Material Health portion of this certification focuses on the elimination or reduction of hazardous chemicals.

Appendix II shows that 26 out of the 59 chemicals identified in this report are banned or limited.

7 Conclusions and Recommendations

7.1 Conclusions

This report has identified several barriers to recycling carpet, with toxic substances being one of the main barriers and the focus of this report. 59+ toxic substances identified in this report have been identified as used in carpets. Exposure can occur via inhalation, eye/skin contact, and even ingestion of dust – leaving vulnerable populations, such as children, particularly susceptible to their toxic effects.

In looking at the regulatory landscape of the identified chemicals, it is clear that much regulatory work still needs to be done in order to confirm these substances as chemicals of concern and to move them through the regulatory process towards risk mitigation by either restricting or banning their use.

For example, undecafluorohexanoic acid - a PFAS identified in this report for its use in carpets sold in the EU - was included on the PACT list of substances to undergo information hazard assessment in November 2015, and only in January 2018 was it added to PACT for risk management options with recommendations that it should be added to the Candidate list of SVHCs. It could be a couple more years before we see this PFAS added to the Candidate list and even longer for its complete ban. This is just one example identified in this report where it becomes clear the regulatory process, while necessary, also hinders the removal of toxic substance from the outset in carpets. Additionally, while some third-party certifications for carpets restrict or ban many toxic substances in carpets, they will never make up for strong legislation.

7.2 Key findings from the report

Chemicals of concern identified, evaluated, restricted, and/or banned under REACH

- 12 chemicals of concern identified in Appendix I of this report have no activity under Annex III, CoRAP, or PACT nor have they been added to the Candidate, Authorization or Restricted substance lists. For example, many of the aromatic amines identified in the report are listed under the CLP as possible category 2 carcinogens, mutagens, and reproductive toxicants yet none of them have gone through the evaluation process to identify proper risk management measures, such as possible restriction and/or ban.
- 10 substances have been identified as potential chemicals of concern under Annex III, yet have no further regulatory action at this time. These substances are suspected to be CMRs and/or PBTs under Annex III and should undergo further evaluation under CoRAP to substantiate these initial concerns and where

applicable, these substances should be further prioritized for risk management measures, such as restriction and/or ban.

- Only 6 substances identified are identified as SVHCs on the candidate list which have not been moved to the Authorisation list.
- Only 4 substances, which are phthalates, have been placed on the Authorisation list and banned from commerce.
- Only 12 substances are restricted for their use in carpet materials. Some substances are restricted under REACH, but their restriction does not apply to carpets. For example, the phthalate DINP is restricted for plasticized material in toys or childcare articles which can be placed in the mouth by children and does not extend this restriction to carpets that may leave children and others highly exposed.
- Additionally, many substances are restricted in toys or children's articles – such as lead (Pb) and DINP - but do not extend to carpet despite the large portion of time children spend on carpets.
- As part of some restrictions, such as nonylphenol ethoxylates, the limits are less stringent for recycled materials.

Chemicals of concern identified, restricted and/or banned by certification schemes

- The Blue Angel certification, with the Nordic Swan as a close second, restricts/bans the most substances (51 out of 59) while industry-led GUT label restricts/bans the least (13 out of 59).
- Certifications do not appear to be aligned on the restriction/ban on flame retardants. Blue Angel is the only certification that bans the use of flame retardants entirely. Nordic swan bans all halogenated flame retardants. However, all other certifications do not ban all flame retardants and are not aligned on the ones they do restrict.
- Essentially no certification restricts the additional aromatic amines that have been identified in the report as chemicals of concern and breakdown products from azo-dyes, suggesting more work is likely needed to understand the hazards associated with the >10,000 dyes and pigments[322] and their disperse use.
- Only Nordic swan places a limit on the use of isocyanates in carpet materials; For Blue Angel it is unclear whether isocyanates used in the manufacture of PU are considered.
- Nearly all certification schemes limit or ban the use of nonylphenol ethoxylates, with the exception of GUT which has not restriction or ban.
- Organotin compounds have been restricted or banned in their use for most certifications, with the exception of GUT. However, some of their replacements which have also been identified as potential chemicals of concern are not yet restricted or banned.
- Lead, cadmium and mercury are limited or banned in all carpet certifications.

Based on the research and these findings, we have prepared the following advice for policy makers, manufacturers, carpet certifiers, as well as consumers.

7.3 Advice for Policymakers

That restricting and/or banning of substances is important in supporting a non-toxic circular economy in carpets. However, as pointed out in this report, the regulatory process to restricting and/or banning is often long and inefficient. However, there is legislation currently that can be strengthened to support non-toxic in carpets (such as CMR in textile restriction), while new legislation is put in place to support non-toxic recyclable carpets such as a Carpet Directive similar to the Directives that govern toys and electronics.

Policy Coherence needed to Ensure Highest level of Human and Environmental Health

- The EU must confirm its strategy towards a non-toxic environment under its EAP [2], [323] commitment in the 2018 report.
- Clear guidance on how to progress the use of safer alternatives and avoid the case of regrettable substitutions should be addressed.
- Clear guidance on what can be done to assess and avoid cumulative exposure should be addressed.
- Clear evidence on the importance of addressing chemicals of concern as related to their impact on vulnerable populations such as infants and small children should be included.

REACH Related Recommendations

Restrict and/or ban Appendix I substances where applicable: For substances listed in Appendix I that do not qualify as SVHCs in their own right, Member States should assess their exposures and propose applicable restrictions in carpet and carpet materials. In proposing a restriction, Member States should submit an Annex XV dossier via their national REACH Competent Authorities.

For substances that qualify as SVHCs listed in Appendix I, Member States should nominate them for inclusion on the Candidate List. In proposing a substance to be identified as a SVHC, Member States should submit an Annex XV dossier via their national REACH Competent Authorities.

Anyone submitting dossiers for the identification of SVHCs and dossiers proposing restrictions (Annex XV dossier) has to give notice of their intent to do so in the Registry of Intentions (RoI) at least six months prior to the intended submission date.

Out of the total 59 substances identified in this report, only 6 are on the SVHC Candidate list (that have not been placed on the Authorization list), only 4 are on the Authorisation List and banned from commerce, and only 12 are restricted.

Strengthen REACH Regulation:
The shortcomings of the identification, evaluation, authorisation, and restriction of chemicals of concern under REACH should be addressed:

- **Identification process**: registrants must submit better quality dossiers and ECHA needs to ensure their quality in order to best identify chemicals of concern early in the regulatory process; where information exists that a chemical presents itself as a chemical of concern, the process should be optimized in order for the processes of substance evaluation, restriction, and/or ban to take place more quickly.
- **Evaluation process**: evaluating chemicals of concern for their hazards and developing risk mitigation strategies (Authorisation and Restriction) is a necessary but long process; development around this area is necessary to ensure chemicals of concern quickly move through the evaluation process so they can be restricted or banned.
- **Authorisation process**: despite the ban on many SVHCs, these substances can still appear in imported articles and waste streams; guidance on how to ensure the safety of imported products and waste streams will be necessary.
- **Restriction process**: similarly to Authorisation, it is uncertain in many cases how enforcement is ensured for restricted chemicals in articles and guidance should be provided.

ECHA should leverage existing expertise to encourage innovation in the identification of alternatives: The phase out of toxic substances can only be achieved where effective and safe alternatives exist[6]. Therefore, it is recommended that ECHA establish a team of experts/technical committee which would prioritize chemicals of concern where no identified viable safer alternative currently exists and work towards the identification of safer alternatives. As alternative chemicals are assessed and/or developed, their properties should enable safe and efficient waste treatment, particularly for recycling. Additionally, the focus for alternatives should go beyond new chemistries and focus on new technologies that may assume the same functionality as the toxic chemicals they should replace.

ECHA should provide carpet specific guidance on calculating the presence of SVHCs in carpets as well as require a minimum set of safe use information: As part of the REACH regulations, article producers should provide downstream users with safe use instructions when a SVHC is present >0.1% by weight of the article. This becomes nearly impossible for most complex article producers, and specific guidance on how to calculate the presence for SVHCs in carpets should be provided in the ECHA guidance.

Additionally, the calculation of SVHCs in articles should be additive. Under the current regulation, if one SVHC is present at 0.05% and another SVHC is present at 0.05% in an article, no safe use instructions are required. Therefore, the regulation should be additive; when the presence of two or more SVHCs are present in articles at >0.1% by weight, the article should be provided with safe use instructions.

Where the presence of multiple SVHCs is >0.1%, safe use instructions should be required to include identification of the SVHCs driving concern, regardless of their individual concentrations. A minimum set of information should be *required* as part of the safe use instructions and include areas of concern across an articles life cycle such as safe handling, use, unintended uses, possible exposure routes, as well as proper recycling and disposal.

Ensure the same level of safety for imported articles as those manufactured within the EU: Products imported into the EU should adhere to the same regulatory requirements as products manufactured within the EU, such those addressed under REACH legislation, and be better enforced at the border.

Include textile floor coverings in the proposed CMRs in textiles Restriction under REACH: The CMR proposed restriction in textiles should go beyond clothing and apparel and include textile floor coverings considering the long-term exposure to chemicals over many years resulting from substance migration and carpet abrasion. *The restriction should also go beyond CMRs and include endocrine disruptors and substances of equivalent concern*.

Chemicals and the Circular Economy Recommendations

Ensure proper health protection under the circular economy

Avoid the recycled material vs. virgin material double standards to ensure proper health and safety: The EU needs to ensure the same level of human and environmental protection for recycled materials as they do with virgin materials. Recyclable materials should not perpetuate the use of hazardous chemicals at increased concentrations. Therefore, when restricting and setting limits for chemicals under REACH, it is recommended ECHA set the same limits for recycled materials found, which would also apply to carpet materials, as consumer health and safety should not be compromised for resource efficiency. Materials that do not meet these limits, as identified through analytical test methods, should either be treated such that the substance is removed, or the material should not be eligible for reuse or recycling.

Require measures to protect from unknown hazardous chemicals in recycled materials: Substances such as PFOA and PFOS were once not understood to be hazardous and consequently remained unregulated. While we continue to recommend the removal of known hazardous chemicals from commerce, the continued investigation of safer alternatives, as well as the replacement of these hazardous substances with safer alternatives – we recognize that some substances will still be placed on the market without a full understanding of their hazard profiles.

Should the substances be discovered to be hazardous after already being placed in products meant to be recycled, it is recommended that the EU establish risk based measures of the types of products these recycled materials containing these substances are allowed to be used in. It is recommended that the recycled materials containing these substances do not find their way into carpets given the potential for substance migration, as well as other potential exposure due to the daily abrasion of carpet over its lifetime.

Reconsider proposed derogation for second-hand articles as part of the proposed CMRs in textiles restriction: As previously stated, it is recommended that carpets be added to the CMR in textiles restriction proposal. Per the restriction proposal, the European Commission has proposed a derogation for second-hand articles stating it would be difficult to enforce the CMR restriction in recycled textiles because 'managing chemicals in recycled materials would be difficult; as it would be difficult to verify whether the chemical was already present in the recycled materials or added afterwards.' The Commission should reconsider this derogation on recycled textiles as to not promote a toxic circular economy.

Product Specific Legislation Recommendations

Introduce Extended Producer Responsibility (EPR) for carpet: It is recommended that, as the EU Circular Economy Package requirements are finalised and transitioned into law in each of the participating countries, Member States consider the introduction of an obligatory EPR scheme for carpet, to cover the costs of responsible end-of-life management options and use modulated fees to incentivize recyclable, reusable and toxic-free carpet - as it's been used in a similar way for other EPR (e.g. packaging, WEEE)

The European Commission (EC) could use the framework of the Circular Economy Package to set out common principles and targets around EPR for carpets. This may lend itself toward a Directive similar to those that exist for packaging, WEEE, etc. The Member states could then transpose the "Carpet Directive" into national law.

The European Commission should establish a "Carpet Directive" that meets minimum chemical and resource efficiency requirements: The general provisions of the Toy Safety Directive define what constitutes a toy, sets specific requirements for chemicals, outlines technical documentation requirements, and sets forth essential safety requirements. These provisions are in place so that children who buy, play, or use toys can do so safely and appropriately. It is recommended that a directive similar in approach also be established for carpets. At minimum, the Carpet Directive should establish the following:

- Define what constitutes carpet
- Define obligations for carpet suppliers, manufacturers, importers, and distributors
- Chemical safety criteria such as restriction or banning of specific substances in both virgin and recycled materials (please refer to Appendix I of this report for inclusion to this list)
- Require appropriate documentation that ensures proper material and chemical management have be done to ensure the presence of toxic chemicals are properly managed throughout the supply chain
- Set minimum eco-design requirements (see below)

- Transparency and/or labelling requirements

Ideally a Carpet Directive would integrate health and circular economy aspects at once, so in that case the EPR and eco-design elements are best integrated within such directive, to ensure safe & recyclable design.

Given the amount of time small children spend on carpets and their vulnerability to chemical exposure - through the inhalation of VOCs, ingestion of carpet (micro) fibres through their hand-to-mouth behaviours, as well as increased skin contact in carpets identified throughout the report - warrants the introduction of such a directive to ensure the same level of protection as the Toys Safety Directive.

Set complementary minimum standards for the eco-design of carpets: Given the complex nature of carpets and the various materials and consequently chemical uses in their manufacture, it is recommended that a minimum set of standards be established at the EU level governing eco-design to ensure that carpets avoid the landfill and instead are designed with the circular economy in mind. Therefore, as part of the proposed Carpet Directive, the minimum standards for eco-design are recommended as follows:

- Multi-fibre carpets should only be allowed for use when extended producer responsibilities initiatives have been in place to ensure appropriate take back procedures for end of life removal where manufacturer will sort fibres for proper recycling
- Restrict and/or ban the use of all chemicals identified in Appendix I
- PVC should be banned from use as a material in carpet
- Materials, such as adhesives, that impact recycling should not be used

Re-introduce an ambitious EU eco-label for textile floor coverings: While it is recommended that a minimum set of regulatory requirements governing chemicals, design, and EPR be put in place for carpets, it is further recommended that the EU re-introduce an ambitious EU eco-label for textile floor coverings for front runners in the carpet market. The re-introduction of an EU eco-label for textile floor coverings would limit or ban all chemicals of concern in virgin and recycled materials and include the 59 substances identified in this report. Additionally, the EU eco-label would establish a set of robust design criteria so carpets can be recycled at the end of life and would go above and beyond any regulatory requirements.

Chemicals in the Workplace Recommendations

Strengthen the Carcinogen and Mutagen Directive: While we continue to recommend the removal of known hazardous chemicals from commerce, the continued investigation of safer alternatives, as well as the replacement of these hazardous substances with safer alternatives – we recognize this process could take years and that many of these substances used are currently necessary for the manufacture of many materials and products (i.e. antimony as a catalyst for polyethylene terephthalate (PET)).

As these potentially hazardous materials and chemicals continue to be used, it is important to ensure worker safety. Those working in the carpet industry – particularly where cutting, grinding, heating, recycling of carpet materials takes place - are particularly vulnerable to exposure and should be better protected under existing legislation. Therefore, it is recommended that EU strengthen the Carcinogen and Mutagen Directive. First, it is recommended this Directive be extended to consider not only carcinogens and mutagens, but also include reprotoxicants, PBTs, vPvB substances, endocrine disruptors and substances of equivalent concern.

Second, the Directive needs to set stricter binding occupational exposure limits (OELs) as there isn't harmonisation within the EU. For example, the EU has a set an OEL of 3 ppm for vinyl chloride (the toxic monomer used to create PVC). Member States may choose to adopt stricter limits, such as France, which has set a vinyl chloride OEL at 1 ppm. Provisional agreements are currently in place to set OELs for several carcinogens, however, this list should be expanded to ensure the highest level of worker protection[324].

Incentivisation Recommendations

Incentivize innovation in plastic recycling: Many of the materials used in the manufacture of carpets are synthetic plastics materials. While recycling is possible in most cases, there is often technical problems associated with their recycling often resulting in the downcycling of plastics or the inability to recycle/downcycle plastics at all. Particular technical challenges for carpets include the mixing of different polymers in materials as well as the additives and chemical contaminants that may impact toxicity and performance of otherwise recyclable materials. Although, incentives for high quality and closed loop recycling might drive the market towards the development of technologies to isolate fibres in a good enough quality to facilitate recycling, to separate polymers, or to develop new added value applications which can take mixed polymer feedstocks; all of which needs to go hand in hand with real efforts to design carpets better.

Promote industry and stakeholder collaboration: Under Horizon 2020 the EU programme for research and innovation - the Europeans Commission' Directorate-General for Research funded a €10m pilot project in Finland supporting the electroplating industry. ECHA organized an 'innovation workshop' where electroplaters, suppliers, customers, alternative solution providers, and funding support organizations came together and generated eight project ideas that could be funded to support safer alternatives to the currently used hazardous substance in the electroplating industry.

ECHA has stated that supply chain workshops could be repeated in other member states and for different industries.

Incentivize safe chemistries: Incentivize safer chemistries and materials by offering subsidies and/or increase tax on facilities and/or products that contains hazardous substances to off-set the hidden costs of hazardous substances – such as increased health costs - and to encourage the use of safer chemistries and materials.

For example, the successful Danish tax on phthalates in PVC. The Danish government recently stated that it would be scrapping this tax because "the tax is no longer having any 'significant behavioural effect on health or the environment, largely due to the declining use of phthalates". Additionally, it was discussed that because the 'tax rate remains the same, regardless of the concentration or type of phthalate, there is no incentive for companies to reduce or switch to less problematic ones'[325].

It is not clear what other options were considered to continue to incentivize companies to switch to less problematic substances prior to the decision to scrap the tax. Therefore, it is recommended that this tax on phthalates and PVC remain in place in Denmark and be extended to include the use of other SVHCs, as well as the substances identified in Appendix I of this report. Where these substances remain in use, tax monies generated from their use should be earmarked/directed towards initiatives around safer chemistry initiatives – such as the funding of safer alternative innovation projects or establishing an alternative assessment technical committee. It is also recommended that other Member States adopt such policy with regards to the taxation on the use of chemicals of concern such as those identified in Appendix I in this report. Caution should be taken to ensure this approach does not dis-incentivize supply chain communication of chemicals of concern in carpets.

7.4 Advice for Manufacturers

The report has indicated many regulatory gaps that exist and act as barriers to the safe recycling of carpets. These regulatory gaps focus on the slow process to identifying and consequently removing toxics in commerce and consequently in the manufacture or finishing of carpets. Therefore, creating both detoxified and recyclable carpets currently rests with the manufacturers. The recommendations in this section help to identify areas where manufacturers can achieve detoxified and recycled carpets are part of meeting circular economy objectives towards resource efficiency.

Chemical Specific Recommendations

Remove all SVHCs and chemicals identified in Appendix I of this report from carpet: Phase out the use of PVC and industry's most toxic substances included in Appendix I of this report. Adhere to industry's strictest VOC and heavy metal standards. Switch to safer alternative chemical solutions. If safer chemical alternatives are not currently available and/or technologically feasible, look for new technologies or switch to different materials.

Ensure the safety of incoming recycled materials: Incoming recycled content should be tested to avoid levels of hazardous legacy chemicals. Manufacturers should request analytical information from their suppliers to ensure SVHCs or any substances identified in Appendix I are not present. Manufacturers could also implement

Circular Economy Recommendations

Promote non-toxic recyclable eco-design:

- Move away from unrecyclable or difficult to recycle materials in carpets such as certain adhesives, polyurethane, SBR, and bitumen.
- Use single fibre materials to increase recovery and recyclability of carpets.
- Avoid the use of SBR binders within the carpet structure which provide a major barrier to recycling, and replace these with non-toxic adhesives which allow for easy separation of face and backing fibres.
- Promote the use of releasable adhesives for installation, such as those based on acrylic copolymers.
- Make carpet backing from same material as face fibre, or easily separable.
- PVC, while not extensively used in the EU, should be phased out completely.
- Innovate new carpet designs with a detoxified circular economy in mind.

Collaborate to solve the carpet industry's barriers to recycling: Collaborate with others in the carpet industry to solve industries most undesirable problems - such as toxic additives in the manufacture of carpet. The Green Chemistry and Commerce Council (GC3) has created a collaborative innovation project governing preservatives where industry and researchers are currently innovating new green chemistries for safer preservatives. Continue to move industry towards the use of polyamide-6, PET, and other recyclable yet less hazardous materials.

Transparency Recommendations

Communicate across the carpets life cycle: There is a need for improved communication between the various actors in a carpets life cycle. The information available on chemical content in carpet materials is rarely passed on from manufacturers to consumers, and even less likely to waste/recycling facilities. This lack of information makes it difficult to recycle carpet safely[326]. Therefore, it is recommended that carpet manufacturers work towards the use of an information exchange system, such as the Chemicals in Products Programme (CiP[327]), that enable all actors in a carpets supply chain to input material and chemical related information.

Communicate within your supply chain: Complex articles such as carpets are typically made from many materials, include many chemicals, and may be sourced from many suppliers. As a result of this complex supply chain, information may be lost without proper communication and consequently a level of uncertainty exists whether the presence of chemicals of concern exists. To mitigate such risks, manufacturers should implement a good procurement strategy by doing the following:

- Keep a bill of materials (BOM) used in the carpet (e.g. carpet fibres and backing material) and make it publicly available.
- Keep a chemical inventory of all substances used in carpet (e.g. chemical additives in specific materials and/or post-treatment formulations) and make it publicly available.
- Contact suppliers and explain you are requiring SVHC-free formulations as well as non-hazardous or less-hazardous chemicals and request safety data sheets (SDSs).
- Work with suppliers on understanding their chemical formulations and how they impact your carpet, particularly understand how they impact potential hazard and recyclability and/or;
- Shop around for alternative solutions if current supply chain cannot offer the best solutions.
- Ensure your supplier manufacture facilities ensure the highest level of worker safety (i.e. ask about facility compliance, request reports, and request information on standard operating procedures they have in place to ensure worker safety).

Collaborate to solve the carpet industry's barriers to recycling: Collaborate with others in the carpet industry to solve industries most undesirable problems - such as toxic additives in the manufacture of carpet. For example, the Green Chemistry and Commerce Council (GC3) has created a collaborative innovation project governing preservatives where industry and researchers are currently innovating new green chemistries for safer preservatives. Continue to move industry towards the use of polyamide-6, PET, and other recyclable yet less hazardous materials.

Promote chemical transparency through labelling: In addition to the concerted efforts around communication across a carpets life cycle and supply chain, it is recommended that manufacturers properly affix a label or QR-code to their carpets so downstream users – primarily so those in carpet removal and disposal can ensure the appropriate end of life mechanism to ensure the highest level of safety. Minimum label requirements should include the following:

- Manufacturer and related contact information
- Product identification and year of manufacture
- Material and chemical related information
- Carpet end-of-life treatment options, especially reuse and recycling options

Worker Safety Recommendations

Ensure the highest level of worker safety: workers in many chemical or carpet manufacturing operations are one of the most highly exposed populations to the chemicals in these facilities. Per the Carcinogen and Mutagen Directive, "Employers must reduce the use of carcinogen or mutagen, particularly by replacing it, as far as technically possible, with a substance, preparation, or process that is not dangerous or is less dangerous."

Provide chemical, material and product specific safety training: Those working in the installation and removal of carpet are highly exposed populations to the hazardous chemicals found in carpets and should be provided with optimal training to ensure their health and safety. For example, the EU has placed a restriction on isocyanates requiring companies handling isocyanates, which includes those handling PU and PU foams, to provide appropriate worker training to avoid new incidents of respiratory sensitization.

Carpet manufacturers should ensure worker protection such as proper personal protection, ventilation, and safe handling requirements are set and met across the carpets life cycle (manufacture process, storage, distribution, transportation, installation, removal, recycling, as well as other end-of-life scenarios).

7.5 Advice for Carpet Certifiers

The report has indicated many regulatory gaps that exist and act as barriers to the safe recycling of carpets. These regulatory gaps focus on the slow process to identifying and consequently removing toxics in commerce and consequently in the manufacture or finishing of carpets. Where current gaps exist in legislation, certification schemes can build upon and create requirements to close these gaps. The recommendations in this section help to identify areas where carpet certification schemes can assist the process in achieving detoxified and recycled carpets, again, in order to meet circular economy objectives towards resource efficiency.

All certification schemes should follow the strictest standards: Each certification scheme should expand their red lists to include substances identified in Appendix I if ban or limit is not already set. Adopt industries strictest VOC standards. All SVHCs should be banned from their use in carpets. For carpet certifications that includes the ban of SVHCs in carpets such as Nordic Swan and Blue Angel.

The GUT should update its on ban on SVHCs to include the most recent SVHC list and do so on an annual basis. Continually update your certifications and to horizon scan for new substances that may be of concern (such as reviewing the Registry of Intentions) and consider them for possible inclusion to be banned or limited as part of your certifications.

Ban the use of PVC as a carpet material: Ensure carpet manufacturers avoid the use of this material and move towards safer alternatives. In this regard, certifiers should also consider banning the use of phthalates.

Ban the use of identified flame retardants: At minimum, the certification schemes should ban the use of flame retardants identified in this report. The Blue Angel certification recommends ammonium phosphate and expandable graphite to be used as necessary to comply with fire safety requirements.

Set eco-design requirements in attaining certification: When designing carpets, a holistic approach should be taken. In other words, understanding the impacts the carpet has across its life cycle including the sourcing of raw materials to its end of life should be considered when awarding eco-labels. Recommendations for requirements as follows:

- Require raw materials used in manufacture do not contain any chemicals of concern, including those substance lists in Appendix I.
- Favour those materials that require the least number of chemical additives.
- Require raw materials from recycled content be accompanied with origin of plastic and/or laboratory test indicating that no-known SVHCs, or chemicals identified in Appendix I of this report, are present.
- Require carpets be properly labeled in order to trace back for proper end of life treatment.
- Require carpets be designed to be recycled at end of life.

7.6 Advice for Consumers

Owing to lack of regulatory restrictions and/or bans on substances and often insufficient certifications that this report describes, consumers concerned about the potential impact of carpets on themselves and their family, need to be pro-active in engaging with retailers and manufacturers. Although regulatory action is of course very important, consumer pressure can be particularly powerful in making manufactures change their ways of doing business and the materials they use. A growing demand from consumers for floor coverings which are acceptable from an environmental and health point of view, can drive manufacturers to meet this demand or lose market share. Although direct engagement with manufacturers can help drive this, retailers are in a unique position to gauge the needs of their consumers and demand new products to meet changing market needs. This demand can assist in the scaling up of safer more recyclable carpets.

Look for the Blue Angel and Nordic Swan eco-labels: Appendix II in this report shows that the Blue Angel eco-label bans/limits the majority of hazardous chemicals identified in this report, with the Nordic Swan eco-label as a close second.

Consumers should demand information: Under REACH, consumers can request SVHC information on their products and place demand that these be identified and removed. Consumers should continue to place pressure on all carpet certifications to meet the strictest chemical limits. Retailers should be asked to explain their policies in this regard, provide new products to meet changing consumer needs, and provide environmentally acceptable take-back and recycling schemes at end-of-life. In addition, consumers can investigate ways that they can minimise their own exposure and environmental impact through the use of tile carpet in residential application, for instance.

Appendices

I. Potentially toxic chemicals identified as possibly found in EU carpets - Regulatory Position

	Chemical Related Info		European Regulatory Landscape					
CAS	Chemical	Chemical Group	Annex III	CoRAP	PACT	Candidate List	Authorization List (Annex XIV)	Restricted List (Annex XVII)
PFASS: Broad class of chemicals that encompasses thousands of substances and includes groups of PFASs such as PFOA, PFOS (as mentioned in this report) as well as PFBS, PFHxS, PFHxA, PFNA, PFDA, and many others.								
2144-53-8	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate	PFAS	-	✓	✓	-	-	-
17527-29-6	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate	PFAS	-	✓	✓	-	-	-
307-24-4	Undecafluorohexanoic acid	PFAS	✓	-	✓	-	-	-
375-22-4	Heptafluorobutyric acid	PFAS	✓	-	-	-	-	-
335-67-1	Pentadecafluorooctanoic acid (PFOA)	PFAS	✓	-	-	✓	-	✓
Flame Retardants								
1163-19-5	decaBDE	Flame Retardant	-	-	-	✓	-	✓
56803-37-3	tert-butylphenyl diphenyl phosphate	Flame retardant	✓	-	-	-	-	-
25713-60-4	2,4,6-tris(2,4,6-tribromophenoxy)-1,3,5-triazine	Flame Retardant	✓	-	-	-	-	-
26040-51-7	Bis(2-ethylhexyl) tetrabromophthalate	Flame Retardant	-	✓	-	-	-	-
115-96-8	Tris(2-chloroethyl)phosphate (TCEP)	Flame Retardant	-	-	✓	✓	-	-
13674-84-5	Tris(2-chloro-1-methylethyl) phosphate (TCPP)	Flame Retardant	-	-	✓	-	-	-
13674-87-8	Tris[2-chloro-1-(chloromethyl)ethyl] phosphate (TDCP)	Flame Retardant	-	✓	✓	-	-	-
1309-64-4	Diantimony trioxide	Flame Retardant	-	✓	-	-	-	-
32534-81-9	Diphenyl ether, pentabromo derivative	Flame Retardant	✓	-	-	-	-	-
38051-10-4	V6 (2,2-bis(chloromethyl) trimethylene bis[bis(2-chloroethyl)phosphate])	Flame Retardant	-	-	-	-	-	-
68937-41-7	Phenol, isopropylated, phosphate (3:1)	Flame Retardant	-	-	-	-	-	-
115-86-6	Triphenyl phosphate (TPP)	Flame Retardant	-	-	✓	-		-

Chemical Related Info			European Regulatory Landscape					
CAS	Chemical	Chemical Group	Annex III	CoRAP	PACT	Candidate List	Authorization List (Annex XIV)	Restricted List (Annex XVII)
<u>Phthalates</u>								
117-81-7	Bis (2-ethylhexyl) phthalate (DEHP)	Phthalate	-	-	-	✓	✓	✓
85-68-7	Benzyl butyl phthalate (BBP)	Phthalate	-	-	-	✓	✓	✓
84-74-2	Dibutyl phthalate (DBP)	Phthalate	-	-	-	✓	✓	✓
71888-89-6	DIHP	Phthalate	✓	-	-	✓	✓	✓
68515-48-0	DINP	Phthalate	-	-	-	-	-	✓*
28553-12-0	DINP	Phthalate	-	-	-	-	-	✓*
26761-40-0	DIDP	Phthalate	✓	-	-	-	-	✓*
117-84-0	DNOP	Phthalate	✓	-	-	-	-	✓*
Dyes: This is a non-exhaustive list of additional aromatic amines that have publicly available data indicating their mutagenicity and carcinogenicity and have been identified as break down products of azo dyes currently found on the market. (16)(17)								
97-52-9	2-amino-5-nitroanisole	Dyes (azo)	-	-	-	-	-	-
99-09-2	m-nitroaniline	Dyes (azo)	-	-	-	-	-	-
99-57-0	2-amino-4-nitrophenol	Dyes (azo)	-	-	-	-	-	-
108-45-2	m-phenylenediamine	Dyes (azo)	-	✓	-	-	-	-
121-66-4	2-amino-5-nitrothiazole	Dyes (azo)	✓	-	-	-	-	-
121-88-0	2-amino-5-nitrophenol	Dyes (azo)	-	-	-	-	-	-
123-30-8	p-aminophenol	Dyes (azo)	-	-	-	-	-	-
156-43-4	p-phenetidine	Dyes (azo)	-	-	-	-	-	-
615-50-9	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	-	-	-	-	-	-
95-70-5	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	✓	-	-	-	-	-
25376-45-8	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	-	-	-	-	-	-
3531-19-9	6-chloro-2,4-dinitroaniline	Dyes (azo)	✓	-	-	-	-	-
Biocides: Antimicrobials								
55406-53-6	3-iodo-2-propynylbutylcarbamate (IPBC)	Antimicrobial	✓	-	-	-	-	-
26172-55-4	5-chloro-2-methyl-2H-isothiazol-3-one (CIT)	Antimicrobial	✓	-	-	-	-	-
2682-20-4	Methylisothiazolinone (MIT)	Antimicrobial	✓	-	✓	-	-	-
7440-22-4	Silver	Antimicrobial	-	✓	-	-	-	-
265647-11-8	Silver sodium zirconium hydrogenphosphate	Antimicrobial	-	-	-	-	-	-
3380-34-5	Triclosan	Antimicrobial	✓	✓	✓	-	-	-
9011-05-6	Urea, polymer with formaldehyde	Antimicrobial	-	-	-	-	-	-

Chemical Related Info			European Regulatory Landscape					
CAS	Chemical	Chemical Group	Annex III	CoRAP	PACT	Candidate List	Authorization List (Annex XIV)	Restricted List (Annex XVII)
13463-41-7	Pyrithione zinc	Antimicrobial	-	-	-	-	-	-
Isocyanates								
9016-87-9	4,4' diphenylmethanediisocyanate, isomere, homologe and mixtures	Isocyanate	✓	-		-	-	-
26447-40-5	Methylenediphenyl diisocyanate (MDI)	Isocyanate	✓	-	✓	-	-	✓ *
5873-54-1	o-(p-isocyanatobenzyl)phenyl isocyanate	Isocyanate	-	✓	-	-	-	✓ *
2536-05-2	2,2'-methylenediphenyl diisocyanate	Isocyanate	-	✓	-	-	-	✓ *
101-68-8	Pure MDI	Isocyanate	-	✓	✓	-	-	✓ *
Nonylphenol & Nonylphenolethoxylates								
84852-15-3	4-nonyphenol, branched	Nonylphenol	-	✓	✓	-	-	-
9016-45-9	Nonylphenol, ethoxylated	Nonylphenol ethoxylates	-	-	-	✓	-	✓
68412-54-4	Nonylphenol, branched, ethoxylated	Nonylphenol ethoxylates	-	✓	-	✓	-	✓
Organotin Compounds								
4253- 22-9; 77-58-7; 10584-98-2	Dibutyltin organotin compounds	Organostannic compounds	-	-	-	-	-	✓
688-73-3; 869-59-0; 892-20-6	Tri-subsitituted organotin compounds (ex. TBT and TPT)	Organostannic compounds	-	-	-	-	-	✓
3648-18-8	Dioctyltin compounds	Organostannic compounds	-	-	-	-	-	✓
Heavy Metals + Compounds: Encompases a broad class of chemicals which may be used in the manufacture of carpet and carpet materials. Please reference 'Heavy metal' chemical profile. Below are the heavy metals (and their compounds) that should be removed from manufacture where possible. The regulatory profiles below do not reflect the full scope of compounds and only the metal themselves.								
NA	Lead	Heavy Metals	✓	-	✓	-	-	✓ *
NA	Mercury	Heavy Metals	-	-	✓	-	-	✓ *
NA	Cadmium	Heavy Metals	-	-	-	✓	-	✓

✓ Present

* restriction is not relevant to carpet

II. Potentially toxic chemicals identified as possibly found in EU carpets - Certification Position

Chemical Related Info			EU Certification Scope				
CAS	Chemical	Chemical Group	Nordic Swan (8)	GUT	Oeko-Tex 100	C2C	Blue Angel (9)
PFASS: This is non-exhaustive list of hazardous PFASs currently on the market. PFASs is a large class of chemicals and covers may classes of PFASs including PFOS, PFOA, as well as many others. Below is a non-exhaustive list of PFASs found in carpets							
2144-53-8	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate	PFAS	Ban (16)	No (6)	No (15)	No	Ban (2)
17527-29-6	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate	PFAS	Ban (16)	No (6)	No (15)	No	Ban (2)
307-24-4	Undecafluorohexanoic acid	PFAS	Ban (16)	No (6)	No (15)	No	Ban (2)
375-22-4	Heptafluorobutyric acid	PFAS	Ban (16)	No (6)	No (15)	No	Ban (2)
335-67-1	Pentadecafluorooctanoic acid (PFOA)	PFAS	Ban (16)(4)	Ban	Limit	Ban	Ban (2)
Flame Retardants							
1163-19-5	decaBDE	Flame Retardant	Ban (16)	Ban	Ban	Ban	Ban (2)
56803-37-3	tert-butylphenyl diphenyl phosphate (TBDP)	Flame retardant	Ban (16)	No	No	No	Ban (2)
25713-60-4	2,4,6-tris(2,4,6-tribromophenoxy)-1,3,5-triazine	Flame Retardant	Ban (16)	No	No	No	Ban (2)
26040-51-7	Bis(2-ethylhexyl) tetrabromophthalate (TBPH)	Flame Retardant	Ban (16)	No	No	No	Ban (2)
115-96-8	Tris(2-chloroethyl)phosphate (TCEP)	Flame Retardant	Ban (16)	No	Ban	No	Ban (2)
13674-84-5	Tris(2-chloro-1-methylethyl) phosphate (TCPP)	Flame Retardant	Ban (16)	No	Ban	No	Ban (2)
13674-87-8	Tris[2-chloro-1-(chloromethyl)ethyl] phosphate (TDCP)	Flame Retardant	Ban (16)	No	Ban	Ban	Ban (2)
1309-64-4	Diantimony trioxide	Flame Retardant	Ban (8)	No	Ban	Limit	Ban (2)
32534-81-9	pentaBDE	Flame Retardant	Ban (16)	Ban	Ban	Ban	Ban (2)
38051-10-4	V6 (2,2-bis(chloromethyl) trimethylene bis[bis(2-chloroethyl)phosphate])	Flame Retardant	Ban (16)	No	No	Limit	Ban (2)
68937-41-7	Phenol, isopropylated, phosphate (3:1)	Flame Retardant	Ban (8)	No	No	Limit	Ban (2)
115-86-6	Triphenyl phosphate (TPP)	Flame Retardant	Ban (8)	No	No	No	Ban (2)
Phthalates							
117-81-7	Bis (2-ethylhexyl) phthalate (DEHP)	Phthalate	Ban	Ban	Limit	Ban	Ban
85-68-7	Benzyl butyl phthalate (BBP)	Phthalate	Ban	Ban	Limit	Ban	Ban
84-74-2	Dibutyl phthalate (DBP)	Phthalate	Ban	Ban	Limit	Ban	Ban
71888-89-6	DIHP	Phthalate	Ban	No	Limit	No	Ban

	Chemical Related Info		EU Certification Scope				
CAS	Chemical	Chemical Group	Nordic Swan (8)	GUT	Oeko-Tex 100	C2C	Blue Angel (9)
68515-48-0	DINP	Phthalate	Ban	No	Limit	No	Ban
28553-12-0	DINP	Phthalate	Ban	No	Limit	No	Ban
26761-40-0	DIDP	Phthalate	Ban	No	Limit	No	Ban
117-84-0	DNOP	Phthalate	Ban	No	Limit	No	Ban
Dyes: This is a non-exhaustive list of additional aromatic amines that have publicly available data indicating their mutagenicity and carcinogenicity and have been identified as break down products of azo dyes currently found on the market. (10)(11)							
97-52-9	2-amino-5-nitroanisole	Dyes (azo)	No	No	No	No	No
99-09-2	m-nitroaniline	Dyes (azo)	No	No	No	No	No
99-57-0	2-amino-4-nitrophenol	Dyes (azo)	No	No	No	No	No
108-45-2	m-phenylenediamine	Dyes (azo)	No	No	No	No	Ban (9)
121-66-4	2-amino-5-nitrothiazole	Dyes (azo)	No	No	No	No	No
121-88-0	2-amino-5-nitrophenol	Dyes (azo)	No	No	No	No	No
123-30-8	p-aminophenol	Dyes (azo)	No	No	No	No	No
156-43-4	p-phenetidine	Dyes (azo)	No	No	No	No	No
615-50-9	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	No	No	No	No	Ban (9)
95-70-5	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	No	No	No	No	No
25376-45-8	2-methyl-p-phenylenediamine; 2,5-diaminotoluene	Dyes (azo)	Limit (8)	No	No	No	Ban (9)
3531-19-9	6-chloro-2,4-dinitroaniline	Dyes (azo)	Ban (16)	No	No	No	Ban (9)
Biocides: Antimicrobials							
55406-53-6	3-iodo-2-propynylbutylcarbamate (IPBC)	Antimicrobial	Ban (5)	Limit	Limit	Limit	Ban
26172-55-4	5-chloro-2-methyl-2H-isothiazol-3-one (CIT)	Antimicrobial	Ban (5)	Limit	Limit	Limit	Ban
2682-20-4	Methylisothiazolinone (MIT)	Antimicrobial	Ban (5)	Limit	Limit	Limit	Ban
7440-22-4	Silver nanoparticles	Antimicrobial	Ban (5)	No	No	No	Ban
265647-11-8	Silver sodium zirconium hydrogenphosphate	Antimicrobial	Ban (5)	No	No	No	Ban
3380-34-5	Triclosan	Antimicrobial	Ban (5)	No	Limit	Limit	Ban
9011-05-6	Urea, polymer with formaldehyde	Antimicrobial	Ban (5)	Ban	Limit (7)	Limit	Ban
13463-41-7	Pyrithione zinc	Antimicrobial	Ban (5)	No	Limit	Limit	Ban
Isocyanates							
9016-87-9	4,4’ diphenylmethanediisocyanate, isomere, homologe and mixtures	Isocyanate	Limit (1)	No	No	Ban	Ban (9)
26447-40-5	Methylenediphenyl diisocyanate (MDI)	Isocyanate	Limit (1)	No	No	No	Ban (9)
5873-54-1	o-(p-isocyanatobenzyl)phenyl isocyanate	Isocyanate	Limit (1)	No	No	No	Ban (9)
2536-05-2	2,2'-methylenediphenyl diisocyanate	Isocyanate	Limit (1)	No	No	No	Ban (9)
101-68-8	Pure MDI	Isocyanate	Limit (1)	No	No	No	Ban (9)
Nonylphenol + Nonylphenolethoxylates							

	Chemical Related Info		EU Certification Scope				
CAS	Chemical	Chemical Group	Nordic Swan (8)	GUT	Oeko-Tex 100	C2C	Blue Angel (9)
84852-15-3	4-nonyphenol, branched	Nonylphenol	Ban (8)	No	Limit	Ban	Ban
9016-45-9	Nonylphenol, ethoxylated	Nonylphenol ethoxylates	Ban (8)	No	Limit	Ban	Ban
68412-54-4	Nonylphenol, branched, ethoxylated	Nonylphenol ethoxylates	Ban (8)	No	Limit	Ban	Ban
Organotin + Tin Compounds							
4253- 22-9; 77-58-7; 10584-98-2	Dibutyltin organotin compounds	Organostannic compounds	Ban (3)	No	Limit	No	Ban (9)
688-73-3; 869-59-0; 892-20-6	Tri-subsitituted organotin compounds	Organostannic compounds	Ban (3)	No	Limit	Ban	Ban (9)
NA	Dioctyltin compounds	Organostannic compounds	Ban (3)	No	Limit	No	Ban (9)
Heavy Metals (mg/kg)							
NA	Lead	Dyes + Pigments	Ban(12)	Limit	Limit	Ban (14)	Ban (13)
NA	Cadmium	Dyes + Pigments	Ban(12)	Limit	Limit	Ban (14)	Ban (13)
NA	Mercury	Dyes + Pigments	Ban(12)	Limit	Limit	Ban (14)	Ban (13)

Ban = certification bans the use of respective substance.
Limit = certification allows substance to be present at certain threshold/limit.
No = no ban or restriction placed on substance in respective certification

Notes:
(1) Only covers PU foams: Isocyanate compounds may only be used in closed processes were recommended/prescribed safety equipment is worn.
(2) No halogenated organic compounds may be used in the manufacture of textile floor coverings (e.g. as binders, flame retardants or dirt-repellent finishes). Allows ammonium phosphates or expandable graphite for flame retardants. As a part of tolerable impurities their contents shall not exceed 1 g/kg.
(3) In PU foam
(4) *Note the national legislations concerning PFOA in the Nordic countries. In Norway PFOA is regulated in «For¬skrift om begrensning i bruk av helse- og miljøfarlige kjemikalier og andre produkter (produktforskriften)», §2- 32.*
(5) Must not be added to fibres or to the finished floor covering for the purpose of achieving a disinfectant or antibacterial treatment or a disinfectant or antibacterial surface
(6) Ban is only for PFOA and PFOS
(7) Oeko-Tex Standard 100 prohibits any detectable formaldehyde.
(8) Nordic Swan: Certification bans SVHCs, CMRs (Class 1A/1B), PBTs, vPvB, and endocrine disruptors
(9) Blue Angel: Bans SVHCs, CMRs (Class 1A/1B), STOT (SE/RE 1), Acute Tox 1/2/3
(10) https://www.kemi.se/global/rapporter/2016/report-8-16-hazardous-chemical-substances-in-textiles.pdf
(11) https://www.sciencedirect.com/science/article/pii/S0273230017301812
(12) Nordic Swan bans these metal compounds from pigments and additives and recycled raw materials
(13) Measured as annual average
(14) On the list of 'Banned List of Chemicals for Biological Nutrients', however, may be use where human exposure is not likely. However, carpet and materials not clearly understood as to whether these would be banned.
(15) Not restricted in decorative material which carpet is considered under the standard; 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate likely falls under the 'ester of fluorinated alcohols with acrylic acid'
(16) Halogenated organic substances, for example organic chloroparaffins, fluorine compounds and halogenated fire retardants

III. Research Methodology

A1.1 Carpet Market and Materials Data

The market data provided in this report are estimates from data collated from several different sources, predominantly from the period 2014–2016. The numbers provided are used to create a broad overview of the EU's carpet market, and that there may be considerable variation in the figures. In particular, the figure of 1,600,000 tonnes of carpet waste arising in the EU per year is thought to be somewhat outdated and we recommend that a further study is undertaken to better understand the waste arising from this product stream; additionally, it is expected that there will be significant year-on-year variability depending on the macroeconomic situation, level of demolition/refit work, and level of sales in previous years.

We stress that the figures developed are based on limited datasets and contain several broad assumptions; therefore, these should be used as guidelines and a foundation for further research, rather than assumed to provide a comprehensive picture of the EU's carpet market.

1.1.1 Placed on Market Data

Placed on market data for EU countries was developed from publicly available data (both square metre and monetary value), based around projected demand of 698m m^2 in 2016[8], [9], [68].

1.1.2 Import/Export

Import and Export to/from the EU was calculated from publicly available trade data from International Trade Statistics, given in goods value[20]. Textile floor coverings fall under Trade Code 57: initially, we excluded product group 5701 (Knotted – the vast majority of these will be rugs) and 570210 (hand rugs) and 570250–570299. As there is a lack of differentiation between carpets and other floor coverings such as rugs and bath mats in the remaining product codes, we adjusted the remaining values, such that carpet accounted for 70 % of the trade value. Lastly, we converted € trade value to square metres using rough estimates of between €5 – €10 m^{-2} depending on the country of origin[29].

1.1.3 Application

Data on application (residential/commercial/other) were based on figures provided in previous Changing Markets reports and in the paper by Wilts *et al.* [8], [9]. Data on broadloom: tile ratios were developed based on separate estimates of uptake for residential and commercial application, assuming minimal uptake in the former[21].

1.1.4 Bulk Materials Estimations

To estimate bulk material usage in the EU, we used estimates for the most widely used face yarn materials [12], [117]. Separately considering broadloom and tile carpet (given their kg m^{-2} differences), we used values collated from several EPDs from a different manufacturers, as well as 'standard' GUT EPDs for different carpet types to provide estimates for the weight of yarn and backing materials[328], [329]. EPDs were used to assess bulk materials; however, there are no requirements to include a bill of materials at the substance level, and most EPDs simply include a generic "additives" quantity.

A1.2 Hazardous Substance Identification & Assessment

The basis of chemicals identified in this report were first found to be present in carpet through the HBN 'eliminating toxics in carpets report'[16] which information was derived from the Pharos database - an independent comprehensive database for identifying health hazards associated with building products[130] and includes health related hazards associated with chemicals in carpets. These substances were cross-checked for their presence in the EU carpet market using the information available on the ECHA website which included referencing substance infocards as well as any proposals and/or decisions made by ECHA which would indicate the substances use in carpets or carpet materials, such as PVC. Additionally, Member State reports were also used to cross-check and identify substances - such as those that can be found on the Swedish Chemicals Agency's (KEMI) website and identified through the report. Substances were excluded or included as a result.

The primary resources used to identify chemical hazards was the CLP as well as information found under the REACH regulation. Other resources were also used to identify possible relevant, non-identified hazard information and to best supplement content to the hazard profiles. Some of the sources include the information derived from the U.S. EPA research efforts as well as the U.S. ASTDR and other reputable publicly available database as referenced in this report.

The regulatory profiles considered a mix of hazard identification frameworks (i.e. CLP, Candidate list) as well as risk management frameworks (i.e. Authorisation list, Restriction list) as well as horizon scanning activities being done in the EU to best identify hazardous substances early and consequently prioritize risk management (Annex III, CoRAP, PACT).

Exposure pathway and disposal information was sourced from a variety of scientific based sources as identified in this report. These resources were meant to add context to human and environmental exposures to these hazardous substances as they occur across the carpets life cycle, as well as how these substances impact end of life scenarios. It is recognized that some areas may be lacking a full robust assessment of all the various pathways and end of life considerations, however, the intent was to show some of the possible and well documented information on exposure and end of life of these substances in carpets.

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