Polyvinyl chloride (PVC) additives: a scoping review

Chief Scientist's Group report

February 2024

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Email: research@environment-agency.gov.uk

Author(s):
Emily Bird, Megan Griffiths, Emma Holden, Daniele Pacifici, Emma Pemberton, Kate Schofield, Eve Tarring

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Research contractor:
Ricardo Energy & Environment
The Gemini Building
Fermi Avenue
Harwell, Didcot
OX11 0QR

Environment Agency's Technical Manager:
Dr Kofi Renner

Environment Agency's Project Manager:
Stacey Bowskill

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Dr Robert Bradburne
Chief Scientist

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Executive summary

Polyvinyl chloride (PVC) is a vinyl polymer and one of the most widely used synthetic thermoplastics in the world, accounting for around 20% of all manufactured plastics. To ensure the polymer is suitable for its intended function, PVC is often blended with other substances. These chemical additives are intentionally added to the plastic and so will be present in the final product. The use of additives improves the efficiency of manufacture or processing, or gives the final plastic material desirable characteristics, such as flexibility.

Heat stabilisers, lubricants, and, in the case of flexible PVC, plasticisers, are always present in PVC articles. Optional additives which may also be present include antistatic agents, antioxidants, blowing agents, fillers, flame retardants, light stabilisers, nucleating agents, pigment agents, slip promoters and viscosity modifiers. Depending on the final product and its function, additives can be present at up to 75% of the total weight of a product, with only 25% consisting of the PVC itself.

Due to its widespread use in numerous articles, concern has been raised about the implications for the environment and human health from the manufacture and use of PVC. Concerns relate mainly to the potential for the release of harmful chemicals during the production of PVC articles, their use, and subsequent disposal at end-of-life. Whilst many of the most harmful substances that have been used as additives in PVC are now restricted under chemicals legislation, there are many more substances which are known to be hazardous to health and/or the environment which are incorporated into PVC.

The Environment Agency commissioned this report to better understand the risk that PVC additives may pose to the environment and/or human health via environmental exposure in the UK. The evidence gathered has been used to identify individual substances or substance groups which cause the most concern and identify critical data gaps. This will help inform the UK Government's strategic approach to identify and address potential issues which may arise from the use of PVC additives.

To fulfil the aims of this project, substances used as additives in PVC that are likely to be relevant to the UK were identified, producing a list of 228 substances. For each of these substances, publicly available evidence on nature of use, amounts used (including both total tonnage and typical concentration range in articles), physicochemical properties and (eco)toxicological data were collated into a database. Published monitoring data for surface and groundwaters, human tissues and indoor house dust was also compiled, with a focus on UK-based studies.

Substances which meet regulatory hazard criteria for environmental persistence, bioaccumulation potential and (eco)toxicity (including known and suspected endocrine disruptors) were identified, along with information on mobility. This was used together with a qualitative consideration of exposure through potential for release from articles to perform a simple first tier qualitative relative risk ranking of the substances and identify priorities for further assessment. The potential for emissions were considered from manufacture through to end-of life. Releases during service life are typically greatest for most additives because of the long in-service life of articles.

Across the functional categories of antistatic agents, flame retardants, heat stabilisers, pigments, plasticisers and slip promoters, 27 substances were identified as a high priority for further assessment. Two of these substances; (tributyl citrate (CAS number 77-94-1) and (Z)-N-octadecyldocos-13-enamide (CAS number 10094-45-8)), are not currently under regulatory scrutiny in either the EU or the UK. A third substance, N-butyl benzene sulfonamide (CAS number 3622-84-2) was nominated by the Environment Agency for Substance Evaluation under the UK REACH Regulations in 2023. Environmental monitoring for these three substances would also be beneficial as no UK monitoring data were found for any of them. Eight PVC additives had insufficient data for a relative risk ranking to be assigned.

Given its widespread detection in surface waters, triphenyl phosphate is also a candidate for further risk assessment in the UK once the Substance Evaluation has been completed under EU REACH (work that was initiated by the UK before EU exit). This substance is used in a variety of materials and is also an impurity in other flame retardants, so this work would extend beyond the use of PVC. Further consideration could also be given to reviewing the plasticiser bis(2-ethylhexyl)adipate for similar reasons.

Bis-(2-ethylhexyl) phthalate (DEHP) is also widely detected but is subject to authorisation in the UK and is also restricted in PVC used indoors. However, there are no controls on imported or recycled PVC articles for use outdoors (such as rainwater collection systems, traffic management infrastructure, hoses, etc.). The continuing widespread detection of this substance could be due to historical uses, but a campaign to measure its presence in imported / recycled articles for use outdoors could provide insight as to whether further controls might be warranted.

Tris(2-ethylhexyl) phosphate, 2-ethylhexyl diphenyl phosphate and (1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]) have been detected in indoor dust, so could also be reviewed from a human health perspective. The latter substance is subject to Substance Evaluation under EU REACH (work that was initiated by the UK before EU exit), so could be reviewed once that work is complete.

An overview of PVC waste streams in the UK is also provided, including waste composition, recycling and waste infrastructure, and end-of-life treatment and disposal processes currently available in the UK. The current challenges faced in PVC recycling are highlighted.

1. Introduction

Polyvinyl chloride (PVC) is a vinyl polymer and one of the most widely used synthetic thermoplastics in the world, accounting for around 20% of all globally manufactured plastics (British Plastics Federation, 2021). PVC is manufactured from salt and oil (accounting for 57% of production) or natural gas (43%) (Plastics Europe, 2019). It was first commercially produced in 1933 and has had widespread uses in multiple sectors ever since, as a result of its properties such as durability and ability to bond with a wide range of additives due to its high polarity (Turner and Filella, 2021). By the end of the 1960s, PVC use had increased significantly. With an average article lifespan of around 50 years, older PVC products are increasingly reaching the end of their lifetimes, and the volume of PVC waste is increasing (Plinke et al., 2000).

PVC is produced in both rigid (unplasticised) and flexible (plasticised) forms, where plasticisers are added in quantities of up to 50% of the total proportion of the material (Turner and Filella, 2021). Due to its versatility and inexpensive nature, PVC has many applications in the building, transport, packaging, electrical/electronic and healthcare industries, specifically in products such as window frames, drainage pipes, cable and wire insulation and floorings (British Plastics Federation, 2021).

To achieve the desired PVC characteristics and make the polymer suitable for its intended function, PVC is often blended with other substances. These chemical additives are intentionally added to the plastic and so will be present in the final product. The use of additives helps to achieve desired physical characteristics or induce a chemical effect during the processing stage which will impact the final plastic (European Commission, 2011). Heat stabilisers and lubricants are used in all PVC products, in addition to optional additives such as pigments, flame retardants and fillers (British Plastics Federation, 2021). Plasticisers are also used to produce flexible PVC. In addition to the functional enhancement of properties, the additives may also assist with prolonging the life of the PVC product (Hahladakis et al., 2018). In some applications, the polymer content of a PVC product can be as low as 25% by weight, with the remaining 75% consisting of additives (British Plastics Federation, 2021).

Due to the widespread use and application of PVC, concern has been raised about the implications for the environment and human health from the manufacture and use of PVC, mainly relating to the potential for the release of harmful chemicals during production, use in articles, and their disposal at end-of-life (Turner and Filella, 2021, European Commission, 2022b). The potential for release of additives is influenced by their physicochemical properties together with other factors and the nature of emissions to the environment varies between different lifecycle stages. During production of both raw materials and PVC articles, handling and processing methods may lead to particulate losses or release through volatilisation. During the product service life, emissions are condition- and technical function-specific. Key factors influencing the potential for release include the degree of contact with water, the rate of volatilisation to air and the production of particulates released by abrasion or degradation. The length of service life of an article, whether it is used indoors or outdoors, dictates the relative influence of these processes.

End-of-life emissions vary according to the mode of disposal and the quantity of additive remaining within the product. Discarding the product is likely to result in any additives remaining within the product being emitted through leaching, volatilisation or by abrasion or degradation (OECD, 2009, Bridson et al., 2021). In landfills, leaching is likely to continue over time, whilst incineration should lead to complete destruction and thus no loss of volatilised additive to the environment (OECD, 2009). Recycling processes may lead to emissions comparable to those observed during production as the cycle continues (Hahladakis et al., 2018).

In the European Union, the European Chemical Agency's (ECHA) work on characterising risk from plastic additives is ongoing. In November 2022, they began an investigation at the request of the European Commission to determine whether PVC and its additives pose a risk to the environment and/or human health through a call for evidence from the industry. This evidence will help to determine whether further European regulatory measures may be required. Their work particularly focuses on heat stabilisers, plasticises and flame retardants and will present information once published on uses and use volumes of PVC, information on end-of-life and on potential exposure. The report will compile evidence from private companies, trade associations, scientific organisations, non-governmental organisations and other stakeholders, and is expected to be published in May 2023 (ECHA, 2022a, ECHA, 2022c).

Some of the greatest concerns around the environmental and human health impacts of PVC have arisen from the use of chlorinated paraffins, phthalate esters, and cadmium- and lead-based compounds that are now subject to regulatory controls (see Section 6.3). The Environment Agency commissioned this report to better understand the risk that other PVC additives pose to the environment and/or human health in the UK. The evidence gathered through this project aims to identify data gaps and identify individual substances or substance groups which cause the most concern. In turn, this will be used to inform UK actions in developing a strategic approach to identify and address potential issues which may arise from the use of PVC additives.

Specifically, the aims of the project were to:

- Determine which additives in flexible and/or rigid PVC are likely to be relevant to the UK.
- Gather information on those additives, including regulatory status, typical concentrations of the additives present within PVC, physico-chemical properties that influence environmental fate and behaviour and (eco) toxicological data.
- Provide a summary of trends in the PVC market, including information on alternatives to the most hazardous PVC additives.
- Collate and present monitoring data from the environment, indoor air, and human biomonitoring for the additives, where available.

- Identify which stage of the PVC lifecycle gives rise to the greatest levels of additive release.
- Summarise PVC waste management practices in the UK.

By gathering substance data, we were able to carry out a relative risk ranking exercise to identify the substances and substance groups which may pose the greatest risk to the environment and human health through environmental exposure. Background information on the PVC market and waste management practices has also been gathered to develop a broader context and understanding of PVC use in the UK. Information gathered on the 228 PVC additives identified as likely to be relevant to the UK are described in this report in the following chapters.

2. Data Collation and PVC Additive Categories

The following sections describe the data collated for each substance studied in this project and the data sources used. Where available, the following data have been compiled for each substance:

- Substance name and identifiers (CAS, EC number)
- Nature of use: primary function, polymer type, typical concentration, use patterns, emission scenarios.
- Regulatory status including tonnage information for EU and UK REACH registrations
- Substance information: molecular weight, substance type (inorganic, monoconstituent, substance of unknown or variable composition, complex reaction products, or biological materials (UVCB), organometallic)
- Physicochemical properties such as water solubility, vapour pressure and n-octanol–water partition coefficient (K_{ow})
- Information on biodegradation, potential to bioaccumulate and mobility.
- Ecotoxicological data (lowest endpoint)
- Human health hazards as identified under the EU Classification, Labelling & Packing (CLP) Regulations (ECHA, 2022b)

2.1 Functional categories

There are four categories of additives used in the manufacture of PVC:

(i) functional additives such as stabilisers, flame retardants and plasticisers;
(ii) colourants;
(iii) fillers;
(iv) reinforcements.

They are designed to modify the plastic to add desirable attributes based on its intended purpose. Some additives present within PVC may have dual functions; for example, some flame retardants have a secondary function as a plasticiser within flexible PVC.

The 4 main groups of additives commonly used in PVC are briefly described in Table 2-1 below. More detail about specific functions can be found in Table 2-2.

Table 2-1. Summary of the main categories of PVC additives

Additive category	Description
Functional	Functional additives are added during manufacturing to give desired properties to the plastic for its specific function. This includes but is not limited to **anti-static agents** added to prevent the build-up of static electricity in electrical insulating plastics; **flame retardants** used to prevent ignition and/or subsequent spread of flame in combustible plastics; **nucleating agents** used for the effective formation of foamed plastic materials; **plasticisers** used to add a flexible, stretchy, soft nature to plastic materials; **stabilisers** used to maintain polymer integrity or other properties at desired levels.
Colourants	Colourants comprise both **pigments** and **dyes** used to add colour to plastic. Dyes are low molecular weight organic materials that dissolve in the plastic to create an even distribution of colour, e.g., hydroxybis(phenylazo)benzene. Pigments, on the other hand, are fine organic or inorganic particles that form a separate dispersed phase within the bulk of the plastic, e.g., substituted aromatic azo compounds and metal chromates.
Fillers	Fillers are solid powders or fibres added into polymers as a separate phase. They are inert so offer no specific technical functions but can improve processability and reduce costs during polymer production as they are normally cheaper than the base polymer.
Reinforcements	Reinforcements improve the tensile strength and mechanical properties of plastic. They can be powders (e.g., silica, carbon black, calcium carbonate) or fibres (e.g., glass, carbon).

2.2 Identification of PVC additives relevant to the UK market

To identify PVC additives relevant to the UK for further study in this project, we searched the scientific and grey literature for mention of substances used in flexible and/or rigid PVC. Our search was conducted in a systematic and unbiased manner, recording search terms and outcomes for transparency. Information sources searched included the bibliographic databases Science Direct and PubMed and Google Scholar. Grey literature sources included the OECD eChemPortal and publicly available information from ECHA. Publicly available EU REACH registration data and data collated through the mapping exercise carried out as a joint project by ECHA and industry as part of the Plastic Additives Initiative (ECHA, 2018b) were key sources and resulted in a list of over 400 functional additives contained in plastics, considering substances which are registered under EU REACH at greater than 100 tonnes per year. PVC additives registered below 100 tonnes per year may also be potentially problematic, but due to their lower tonnages, these were deemed to be less of a priority and outside the scope of this project. Lower tonnage PVC additives should be considered as part of any further work on this topic.

Using these lines of evidence, we compiled a list of 228 PVC additives relevant to the UK because they are associated with one or more stages of the lifecycle of PVC, from manufacture, through compounding and conversion into articles and subsequent disposal. The list included antioxidants, antistatic agents, flame retardants, nucleating agents, pigments, plasticisers, and various types of stabilisers. A brief background description for each of these functions is provided in Table 2-2. This background information can also be found in the fact sheets for each additive function, which have been supplied as a technical appendix. The full list of PVC additives identified and reviewed as part of this project can be found in Appendix Table 10-1.

Table 2-2. Description of PVC additive functions identified as relevant to the project (OECD, 2009, ECHA, 2020)

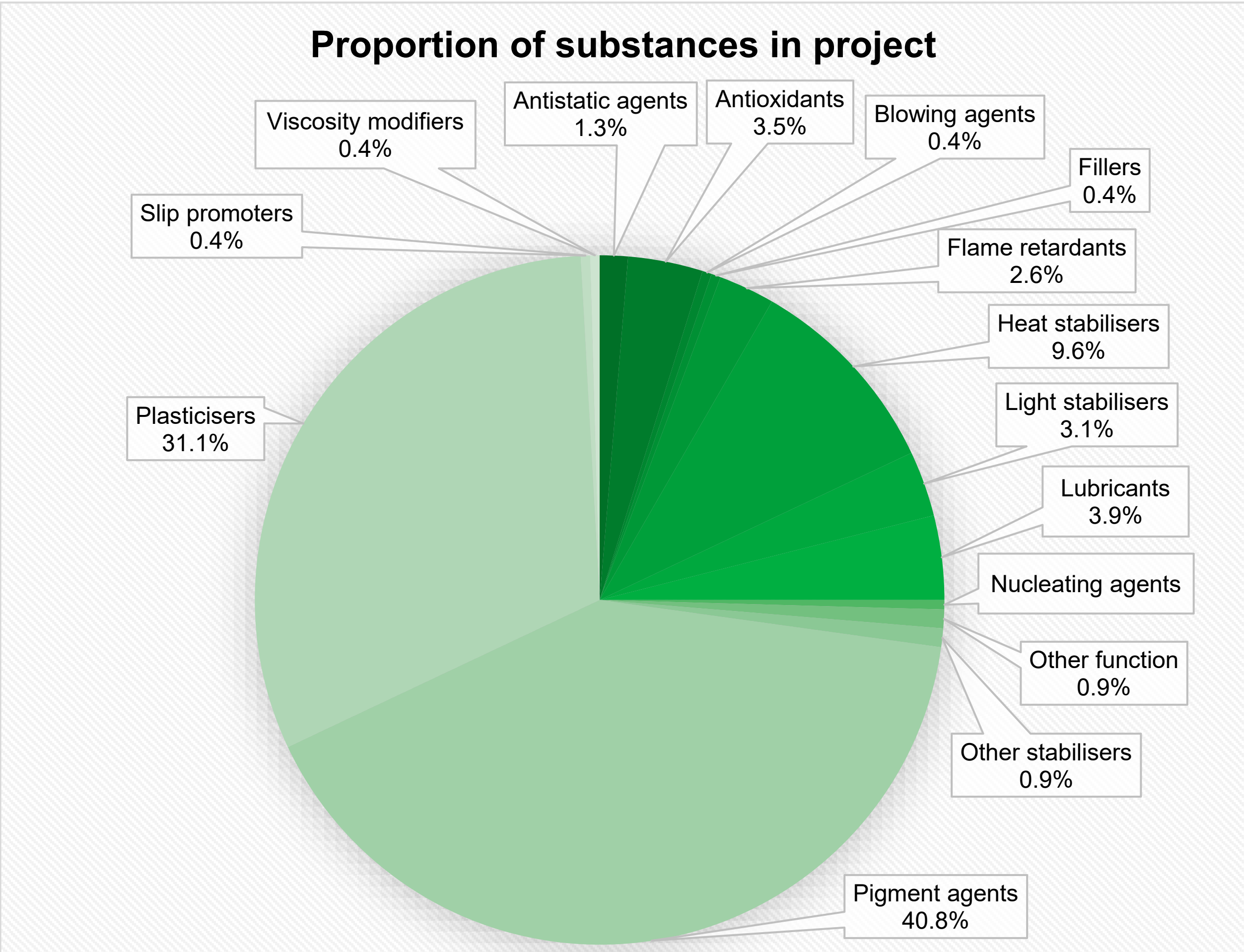
Technical function	Description	No. of substances in list
Antistatic agents	Antistatic agents are used to prevent the accumulation of charge on the plastic's surface (static). There are two mechanisms by which antistatic agents achieve this: 1) acting as lubricants to reduce friction and charge generation, and 2) acting as charge dissipators by creating conductive channels. The polarity of the additive's functional group(s) dictates the mechanism of action. Organic substances containing both polar and non-polar functional groups can act via both mechanisms. Organic antistatics include ammonium salts, amides, amines, and alkyl phosphates and sulfates. Antistatic agents are not designed to remain in the bulk of the plastic but migrate to the surface to fulfil their function. As they only have partial solubility in the polymer, they are susceptible to leaching.	3
Antioxidants	Antioxidants are compounds that slow down the oxidative degradation of plastics following exposure to reactive free radicals generated by ultraviolet (UV) light, heat, or mechanical shear. The aim is to prevent, or at least delay, the occurrence of property changes that may impact the function or appearance of the plastic, such as discolouration, crack formation, tensile weakening, etc. Antioxidant PVC additives are typically two- or three-ring phenolic compounds and include arylamines, organophosphites and phenolics.	8
Blowing agents	Blowing agents, also called foaming agents, are substances that are used in the manufacture of so-called 'foamed' or 'cellular' plastics that are light-weight and thermally insulating. These plastics are produced by the production of gas, facilitated by either physical or chemical blowing agents. Blowing agents can be solids, liquids or gases, and either organic or inorganic. Physical blowing agents are gases, compressed liquified gases, or volatile liquids (e.g., carbon dioxide, chlorofluorocarbons, etc.), whereas chemical blowing agents are substances that thermally degrade to produce carbon dioxide or nitrogen (e.g., sodium bicarbonate, hydrazides, etc.).	1
Fillers	Fillers are powders or fibres added to plastics as a separate phase to change the properties of the end product, such as increased heat resistance, stiffness, or tensile strength. The function of powdered fillers is dependent on the particle size; the smaller the particles the higher the hardness and strength. Fibre fillers improve strength and heat resistance, can be continuous or discontinuous, and may include glass or carbon. As	1

Technical function	Description	No. of substances in list
	with function, emission potential is determined by particle size or fibre shape.	
Flame retardants	Flame retardants are added to plastics to prevent the ignition or subsequent spread of flames, and resultant noxious fumes, in plastics. They can be organic or inorganic, with organic flame retardants usually halogenated, e.g., with bromine. Organic flame retardants, or their breakdown products, can intercept reactive species, whereas inorganic flame retardants can additionally release inert gas or undergo endothermic decomposition. Flame retardants are either fully dissolved (organic flame retardants) or dispersed as a second phase within the bulk of the plastic.	6
Heat stabilisers	Heat stabilisers are added to thermoplastics to prevent their thermal degradation when heated to temperatures above the thermal stability of the plastic, e.g., during the heating of food packaging. PVC, for example, can undergo thermal decomposition at temperatures around 70^{o}C, so require heat stabilisers to maintain functionality. Primary heat stabilisers include mixed metal salt blends, organotin, and lead compounds, while secondary heat stabilisers include epoxy compounds, alkylorganophosphites and beta diketones. The majority are solids, but some may be liquids.	22
Light stabilisers	Light stabilisers are additives used to prevent light-induced oxidation of the polymer that may otherwise occur during its use. Oxidation could cause colour changes, cracking, chalking, loss of tensile strength and more. Light stabilisers act by either absorbing UV radiation, or by ‘trapping’ the free radicals produced by it.	7
Lubricants	Lubricants are required to increase the overall flowability of plastics, thus improving their processability. Lubricants are added to either externally prevent adhesion to moulds during processing, and/or to internally lower viscosity to improve melt flow and reduce friction during the melting or moulding of plastics.	9
Nucleating agents	Nucleating agents are another additive that may be required for blowing during the manufacture of foamed plastics, particularly when physical blowing agents are utilised. Nucleating agents are typically fine suspended particles that form nuclei, offering sites for cell formation, to prevent the formation of super-saturated solutions. The residue of physical blowing agents can serve this function; however, the use of chemical blowing agents will often require the addition of nucleating agents to fulfil this role.	1
Pigment agents	Both pigment agents and dyes can add colour to a plastic, by forming a dispersed phase or dissolving in the plastic, respectively. To achieve an even colour, pigments are normally fine solid particles, which may be organic (e.g., substituted aromatic azo compounds) or inorganic (e.g., metal oxides).	93
Plasticisers	Plasticisers act by reducing shear, thus improving fluidity, during mixing in the production of polymeric materials, ultimately improving their stretchability, softness, flexibility and durability during use. To this end, they are often used in the production of plastic films and food wrap. Over 98% of plasticisers used in plastic materials are used in PVC, with the rest used in polyamides (OECD, 2009). Plasticisers are usually organic liquids or waxy solids, with the dominant group being phthalate esters, used in the production of PVC.	71

Technical function	Description	No. of substances in list
Slip promoters	Slip promoters are additives of low molecular size and partial solubility that migrate to the surface of a plastic to reduce its surface coefficient of friction. This lubricates the surface, easing processing. Examples of slip promoters include fatty acid amides or esters, metallic stearates, and waxes.	1
Viscosity modifiers	Viscosity modifiers are polymeric suspended particles, making them polymers themselves. They have a low affinity for the plasticiser and are used to regulate the viscosity of mixtures of PVC, plasticisers, and solvents.	1

Pigment agents and plasticisers were the largest groups of substances identified and studied in this project, comprising 93 pigments and 71 plasticisers used in PVC. In addition to the technical functions detailed in Table 2-2, two substances categorised under ‘other function’ and two substances under ‘other stabilisers’ were also identified. Figure 2-1 illustrates the different functions of the 228 substances.

Figure 2-1. Proportion of PVC additive functions used in the project.



2.3 Characterising hazards to the environment and human health

Relevant information that could be used to characterise releases and potential impacts to the environment and human health via the environment were collated for each of the 228 substances. This included physico-chemical properties and readily available information on chemical fate and (eco)toxicological effects. Data were collated in an Excel® template, producing a searchable database of publicly available data which is provided separately as a technical appendix to this report.

Our primary source of information was publicly available data on the OECD eChemPortal, and that which is supplied to ECHA in support of REACH registrations and classifications under the CLP Regulation. The data were used at face value since it was beyond the scale of project resources to critically review fate and (eco)toxicological data and assessments for each substance.

Properties of concern identified through this process included persistence (P), potential to bioaccumulate (B), toxicity (T), mobility (M), as well as identifying potential endocrine disruptors (EDs) and human health hazard endpoints, including those which were carcinogenic, mutagenic, and toxic to reproduction (CMRs) based on harmonised CLP classifications and self-classifications notified to ECHA. Criteria used for identification of these properties were the same as those under UK and EU REACH for PBT and vPvB assessment (ECHA, 2017) and the proposed criteria for PMT/vPvM under the EU CLP Regulations (European Commission, 2022a). The criteria used to comment on P, B, T and M properties are defined in Appendix Table 11-1. Endocrine disrupters and those under assessment as an ED were identified using ECHA's endocrine disruptor assessment list (ECHA, 2023).

2.4 Regulatory status of the additives

Where a specific hazard class had been concluded as part of regulatory evaluation under UK (or EU) REACH, the decision was recorded. Additives identified as Substances of Very High Concern (SVHC), and those included on the Candidate List for authorisation under UK (or EU) REACH were noted. Substances requiring authorisation before they are used under Annex 14 of UK (or EU) REACH, and those which are restricted under Annex 17 of UK (or EU) REACH were also highlighted. All substances included in the scope of the project undergoing regulatory scrutiny in the EU have had the dates of any decisions noted in the substance database provided as a technical appendix to this report. Any regulatory decisions under EU REACH made after 1st January 2021 will not be a part of UK REACH and the UK decisions may deviate from the EU.

2.5 Use and tonnage information.

Information on use patterns for the substances, as reported through the EU REACH registration process was also collected from the REACH factsheets published by ECHA to develop an understanding of the nature of use of different articles. The typical concentration of the additive used in PVC was also recorded, with this information identified from ECHA's mapping exercise where available (ECHA, 2018a). The literature was also searched for this information where required; however, information found for these substances was very limited. Other information compiled included tonnage, registration status (including the number of registrations), as well as the Evaluation, Authorisation and Restriction status of the additive. A summary of the data found, and further discussion are provided in Section 4.3.

3. Emission scenarios

The release of substances used as additives in PVC and other plastics may occur across the entire lifecycle, from manufacture, and subsequent formulation of the plastics material, through service life, and finally disposal, dependent on the use and nature of the additive and the plastic article. The potential for release varies according to the technical function of the additive and its physicochemical properties.

The release of additives to their surrounding environment is an unwanted process for both the manufacturer, for whom the loss of additives will shorten the life of a product, for example by loss of strength; and the environment through the exposure of living organisms to the released additives, some of which may have harmful effects (Teuten et al., 2009).

The OECD emission scenario document (ESD) for plastics additives (OECD, 2009) is an important document that provides information on sources, use patterns and releases of chemicals used as additives in PVC in other plastics, and has recently been updated (OECD, 2019). It provides information that can be used to estimate the amounts of an additive released during manufacture of plastics, during their service life, and at end-of-life. An overview of the lifecycle stages is presented in Figure 3-1, and a qualitative summary of potential environmental emissions at each stage is provided in Section 3.1.

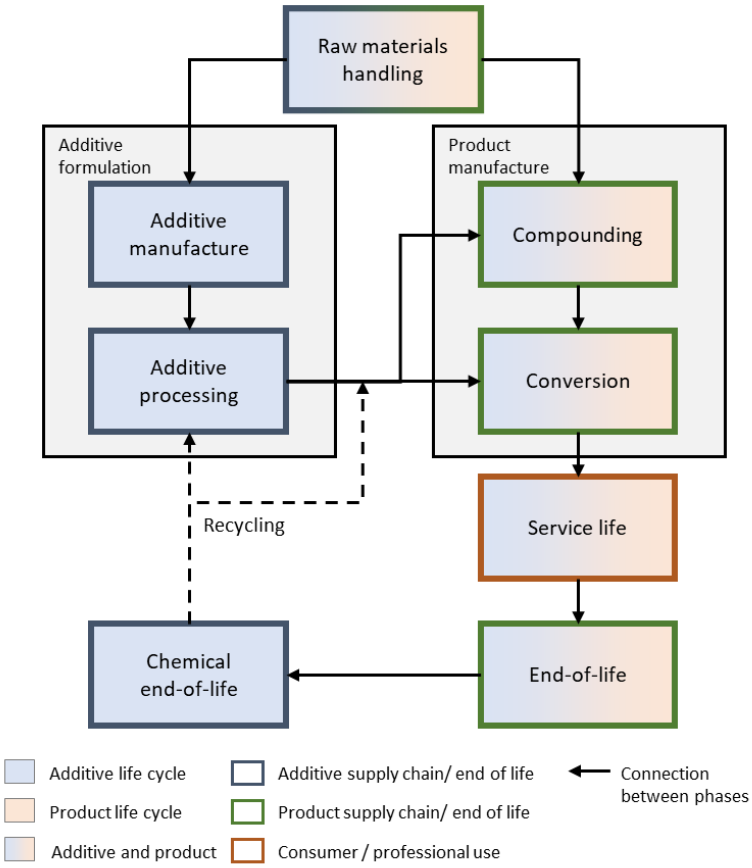
ECHA (2020) produced a document summarising the uses of plastic additives and providing guidance for estimating exposure, based on findings of a collaboration between ECHA and the industry sector called the 'plastics additives initiative'. Information was collated on the use of plastic additives and the extent to which they may be released from plastic articles. As part of the project, a method to compare the relative release potential of different additives was developed, although the relative risk rankings and outputs for individual additives are not publicly available (ECHA, 2020).

A wide range of different additives are added to PVC during the manufacturing process. In most instances, additives are not chemically bound to the polymer matrix (Bridson et al., 2021), and are susceptible to environmental release throughout the lifespan of the final product if they are present in the final material matrix. Releases of additives present in PVC articles into the environment may also occur through wear or weathering of the article and may happen during its service life or at disposal.

3.1 Lifecycle stages

Potential releases of PVC additives to the environment at each lifecycle stage will vary according to the method of manufacture of the additive, formulation of master batch, conversion to finished plastic article and nature of subsequent use of the article (OECD, 2009). Figure 3-1 illustrates the lifecycle of PVC and other plastics.

Figure 3-1. Additive lifecycle stages adapted from OECD (2009)



3.1.1 Additive production

Wiesinger et al. (2021) identified over 10,000 plastic-related substances of which 55% are categorised as additives and 39% as processing aids. Whilst this does not consider the representative usage of each of these substances, it does serve to highlight the high number of substances produced for utilisation as additives in the plastics sector. The extensive range of additives and technical functions they serve means that there are a similarly wide range of additive production methods and techniques. As a result of this, there is very little information available regarding emissions during the production of additive substances, although these should be accounted for separately in the individual REACH registration of each additive.

3.1.2 Product manufacture

3.1.2.1 Raw materials handling

Emissions through the handling of raw materials are most significantly influenced by the physical form of the material. Powders are most prone to particulate emissions through dust generation. Larger solids such as pellets may also release dust because of physical breakdown during transport or handling. Dust and particulates are likely to settle or be collected within extractor systems and disposed of accordingly. This may help to control environmental release, however, if not captured for disposal, it is possible that these are removed during washdown providing a potential pathway to wastewater treatment plants (OECD, 2009). Emissions from liquid and gaseous raw materials are most likely to be via volatilisation and represent the main environmental release at this lifecycle phase.

3.1.2.2 Compounding

Before being converted into plastic artefacts, the plastic polymer is combined with a range of additives under pressure and/or heat in a process called compounding. Compounding can take place during polymer production, as a secondary process, or as a final conversion process. Compounding as a secondary process is the most prevalent mode of additive incorporation and there are various methods by which this may be performed with each having emission potential (Table 3-1). Particulate formation and the release of volatiles and vapours are the main emissions from the compounding process.

Table 3-1. Processes utilised for the compounding of plastic polymer with additives, adapted from OECD (2009)

Method	Details	Emission type
Closed processes		
Blending	Solids or liquids are blended using a high-speed mixer, resulting in a dry powder.	Particulates, volatiles
Tumbling	Mixing of solids with similar particle sizes using a rotating container.	Particulates, volatiles
Gravity mixer	Materials are dropped through a series of baffles several times to mix.	Particulates
Paddle / double arm mixer	Contra-rotating blades create a kneading and folding action. Used for high-viscosity mixes and thermosetting materials.	Particulates, volatiles
Vortex mixer	High-speed stirrers to mix preheated polymers.	Volatiles
Banbury mixer	Additives and polymers are pressed against rotor blades within an enclosed chamber.	Particulates, volatiles
Partially open processes		
Two-roll mill	Two contra-rotating rollers generate a shearing action to knead the material.	Particulates, volatiles

Method	Details	Emission type
Extruders	Polymer and additives are mixed in a hopper or tumblers before being fed into an extruder which shears and heats the material.	Volatiles

3.1.2.3 Conversion

Following compounding, the plastics are ready to be converted into plastic articles through a range of processes. There are two types of plastic materials:

- thermoplastics – processes involve melting the plastic material and forming it into a new shape.
- thermosetting resins – use heat and pressure to form the plastic article.

Figure 3-2. Processes utilised for the conversion of plastic polymers into plastic articles, adapted from OECD (2009)

<table>
<tr><th colspan="2">Method</th><th>Details</th><th>Emission type</th></tr>
<tr><td colspan="4">Closed processes</td></tr>
<tr><td colspan="2">Extrusion</td><td>An extension of the compounding process (Table 3-1), which prepares the plastic by use of shearing and heat for further processing.</td><td>Volatiles</td></tr>
<tr><td colspan="2">Injection moulding</td><td>Accounts for approximately 30% of thermoplastics processing.</td><td>Volatiles</td></tr>
<tr><td colspan="2">Compression moulding</td><td>Mostly used for thermosetting resins.
The prepared compound is heated and inserted into a mould, which is then maintained under pressure through a heating cycle.</td><td>Particulates, volatiles</td></tr>
<tr><td colspan="2">Extrusion blow moulding</td><td>An extruder delivers the extruded plastic (exudate) between two halves of a mould, which are brought together around the hot exudate, air is forced in causing the plastic to melt against the sides of the mould. Waste plastic from the edge of the mould is removed and ground for reuse.</td><td>Volatiles</td></tr>
<tr><td colspan="2">Injection blow moulding</td><td>The plastic is melted, injected into the mould and cooled.</td><td>Volatiles</td></tr>
<tr><td colspan="4">Partially closed processes</td></tr>
<tr><td colspan="2">Film extrusion</td><td>Plastic is extruded as a film, which is then cooled in the open air before being gathered in a reel.</td><td>Volatiles</td></tr>
<tr><td colspan="2">Paper and textile coating</td><td>A layer of extruded film is deposited onto a paper or textile substrate and passed through cooling mills.</td><td>Volatiles</td></tr>
<tr><td colspan="4">Open processes</td></tr>
<tr><td colspan="2">Transforming</td><td>Uses an extruded sheet which is loaded into a frame and heated before being brought into contact with the mould. In some instances, a vacuum may be used to assist.</td><td>Volatiles</td></tr>
<tr><td colspan="2">Calendaring</td><td>Uses a pre-blended compound which is pre-heated and fed into a calendar which compresses and melts the plastic into a thin layer.</td><td>Particulates, volatiles</td></tr>
<tr><td rowspan="3">Fibre reinforced plastic fabrication</td><td>Hand lay-up</td><td>Resin, glass or other reinforcements are deposited with the plastic onto a mould and cured in an ambient atmosphere in the presence of heat.</td><td>Volatiles</td></tr>
<tr><td>Spray techniques</td><td>Reinforcements and plastics are mixed in a sprayer before being delivered to a mould.</td><td>Volatiles</td></tr>
<tr><td>Filament winding</td><td>Reinforcements and plastics are deposited onto a rotating mould which is introduced to an oven for heating,</td><td>Volatiles</td></tr>
</table>

The use of heat to produce articles from both thermoplastics and thermosetting resins results in emissions of volatiles and vapours resulting from the process (Yamashita et al., 2009).

3.1.2.4 Summary of emissions from product manufacture

3.1.2.4.1 Volatiles

Heating is a key aspect of many of the manufacturing processes outlined above and represents a driver behind the emission of additives through the manufacturing stages. A study into the volatility of plasticisers demonstrated that the volatility of additives increased with increasing temperature (Yli-Juuti et al., 2020). Thus, processes that operate at higher temperatures are likely to result in higher emissions of additive-derived volatiles. Volatiles are initially lost to the atmosphere, however, some of the volatile emissions form condensable vapours through oxidation, which could result in their deposition losses as liquid droplets, which may subsequently be released in wastewater.

3.1.2.4.2 Particulates

Particulate or dust emissions are generated from the release of solids at various stages of the manufacturing processes (e.g., mixing and transfer). Some of these particulate losses may initially be to the atmosphere as dust, but a proportion will settle and be removed as either solid waste (presumably to landfill) or in wastewater as a result of 'wash down' processes at manufacturing facilities (OECD, 2009).

3.1.3 Service life

Additives are sometimes destroyed or entirely released during the manufacturing process. However, those which are not may be released into the environment during the service life of the PVC product. Many additives are not chemically bound to the polymer matrix and so these losses are most likely to result from diffuse emissions such as through volatilisation to air and leaching to water. Some emissions will also result from abrasion or degradation of the plastic leading to particulate release (OECD, 2009).

The extent of emission to the environment during the service life of the PVC product is dependent upon the nature of its use, the environmental conditions to which it is exposed, and the timescale over which it is used (Table 3-2). The following product uses with high potential for additive emission are differentiated by ECHA (2020) as:

- uses where the additive will be released from the article matrix during use such as those with high erosion potential, e.g., shoe soles,
- plastic matrices remaining in the environment as waste, such as some agricultural plastics,
- articles with a long outdoor service-life,
- indoor articles with a large surface area,
- articles with significant dermal or oral contact such as food contact materials, toys, gloves, handles and upholstery.

Thus, the specific usage pattern of products should be considered. Products utilised for outdoor applications such as building and construction, agriculture, marine, sports, and transport and automotive are subject to much higher emissions per unit of surface area. In outdoor scenarios leaching is likely to occur when rainwater, surface water or moisture percolates through the plastic material, dissolving and mobilising labile substances (Bridson et al., 2021). A product that is used indoors is only likely to be subject to emissions via leaching if it is regularly washed.

Table 3-2. Representative proportions for main polymer end use and respective life span timescales as reported by the OECD (2009) report.

Use	Proportion of use, %	Timescale, years
Agriculture	9	2
Building and construction	14	>10
Domestic appliances (e.g., white goods)	5	5 to 10
Domestic equipment (e.g., brown goods)	2	5 to 10
Electrical	5	10 to 20
Electronic	3	0 to 5
Furniture	1	5 to 10
Housewares	4	0 to 5
Marine	<1	>10
Miscellaneous	15	0 to 10
Packaging	30	2
Sports	<1	0 to 5
Transport and automotive	13	10 to 20

3.1.4 End-of-life

Once a plastic article has reached the end of its service life it enters the end-of-life phase. The potential for emission during the end-of-life stage will be influenced by the mode of disposal and by the proportion of additive remaining within the product. The mode of disposal is likely to vary depending on the function of the PVC product, with landfill, incineration, repurposing, and recycling all end-of-life options. Disposal options are described in Section 8.

The European Commission's lifecycle assessment of PVC report (European Commission, 2004) divides PVC waste into two major groups:

a) pre-consumer waste, which is generated during production of final and intermediate PVC products and installation waste from the handling or installation of PVC products; and
b) post-consumer waste, which is generated at the end of the product life.

The nature and timescale over which a PVC product becomes waste will be dependent on the specific product and technical function of the additive. Many PVC products have an intentionally long service life and, thus, there is often a considerable time-lag between PVC consumption and PVC waste production.

Disposal to landfill, reuse in other outdoor applications or discarding can lead to leaching of additives and contamination of soil and water and volatilisation to air. Whilst landfill practices should minimise water penetration this represents a further transport pathway that contributes towards wider environmental contamination. Under typical conditions, incineration should lead to complete destruction of organic materials and residues of some inorganic materials remaining in the ash, which can be disposed of as solid waste. Emissions via volatilisation during incineration are considered negligible under the ESD guidance (OECD, 2009), which takes into account the use of state of the art pollution control technologies to limit the release and dispersion of incineration products (Wiesinger et al. 2021).

The recycling and reuse of plastic products represents a positive move towards transition to a circular economy. However, the presence of additives within the plastics may impair recycling processes in terms of the quality of recycling materials as well as the safety, since additives may be released during the recycling processes (Wiesinger et al., 2021). Due to the potential for relatively long product service lives, it is possible that the products being disposed of may contain additives which are no longer permitted for use or not permitted for specific uses, e.g., phthalates are no longer permitted in children’s toys. The identification and separation of different plastic types remains a significant challenge within the recycling industry. Indeed, some of the key stages of the mechanical recycling process, such as extrusion and moulding, require the plastic to be heated to over 200°C, a temperature at which a range of hazardous substances may be emitted as volatiles or vapours (He et al., 2015, Wiesinger et al., 2021).

3.2 Release of additives from PVC

There are several factors that influence the release rate of additives from PVC. These include:

Technical function of the additive. This reflects the likely conditions under which it will be used and influences the rate and nature of emissions. Differing technical functions trigger different exposure considerations in exposure assessment. The function of an additive may be served at the compounding, conversion or during the use lifecycle stage of the product (OECD, 2009).

Concentration of the additive. Substance concentration always plays a role in the release estimation from plastics, with a proportional relationship between release rate and concentration noted (ECHA 2019). High concentrations of some additives such as plasticisers and flame retardants result in higher exposure levels.

Chemistry of the additive. An additive’s chemical properties dictate the way it is incorporated into the polymer matrix. Chemicals incorporated into plastics are generally categorised as either ‘reactive’ or ‘additive’. ‘Reactive’ substances such as coupling agents, cross linking agents, some types of reinforcements and some flame-retardants are chemically bound into the polymer matrix. They are less likely to be released from the article and reach the environment until the product is decomposed, destroyed or under abrasive conditions. ‘Additive’ substances are only mixed with or dissolved in the polymer material and can more easily migrate out of the product. This group includes additives which are added with the intention that they will move towards the plastic surface, such as slip-promoters and anti-statics (OECD, 2009).

Key physicochemical factors driving the emission behaviours of additives are molecular weight, volatility, and solubility in the contact medium. Additives with a very high molecular weight (>700 g/mol and log K_{ow} >9) are typically considered to be of lower concern for release (ECHA, 2015). Indicative values for low release are water solubility less than 0.01 mg/L and vapour pressure less than 0.1 Pa (ECHA, 2020). Dermal contact is an important exposure route for people. According to the Guidance Document on Dermal Absorption (European Commission, 2004), the dermal absorption value for plastic additives could be assumed to be <10 % by default based on physicochemical properties, in particular if the molecular weight is > 500 g/mol and log K_{ow} > 4.5. This refers to the amount of substance that may penetrate the skin under contact with the additive substance and also takes account of the amount of substance remaining in the skin so as to avoid an overestimation during repeat handling (Buist, 2016).

Exposure conditions/intended use. Additional factors will also influence the degree of release of additives and the level of exposure, such as the length of the service life of the article; whether its intended use is indoor or outdoor; use under elevated temperature conditions; dimensions of the article including surface area and thickness; and intensity of oral/dermal contact. Sufficient detail on the apportionment of a total tonnage of an additive across different uses is not publicly available. Once a plastic product enters its service life, knowledge of its chemical composition is often no longer accounted for (Science Advice for Policy by European Academies - SAPEA, 2019). Therefore, for effective risk assessments to be conducted, consideration of environmental emissions and fate under various service life scenarios are required. This may result in the need to assess multiple potential usage scenarios. However, the availability of information pertaining to scale and nature of use in different articles is very limited. Generic release factors have been derived for assessment of environmental exposure and are published in the OECD emission scenario document (OECD, 2019). The complexity of the market in terms of breakdown of information on uses of an additive in different article types has been noted by the ECHA-industry plastics initiative as a hurdle to closing data gaps required for understanding uses of an additive and the related levels of exposure (ECHA, 2018b).

Plastic particle size. Particle size affects surface-to-volume ratio. A larger surface area provides more area from which additives may be released, and also a larger surface for adsorption of small molecules, which increases the potential for the transport of pollutants or the facilitation of bioaccumulation (Shaniv et al., 2021).

Microplastics are defined as plastic particles with a size of <5 mm in length, which may be from a primary source (for instance engineered plastic production pellets), or from a secondary source (occurring as a result of degradation or abrasion of plastic- or plastic-coated products such as textiles or tyres). Microplastics have a large surface area relative to their volume, which means that, under some conditions, they are likely to leach a higher proportion of additives compared to plastics with a smaller relative surface area (Loganathan and Kizhakedathil, 2023, Barnes et al., 2009).

Microplastics are a ubiquitous and complex global contaminant in their own right, differing in size, shape, chemical additives, concentrations, measurements, fates, unknowns, human factors, media influences, actions and behaviours (Science Advice for Policy by European Academies - SAPEA, 2019). This, combined with their large surface area, means that microplastics serve as an effective but difficult to characterise vector for additives and other environmental contaminants by enabling their transfer to multiple environmental compartments, including marine sediment (Lubecki and Kowalewska, 2019). The longevity of plastic within the environment means that there is potential for additives to be leached over a significant timescale. The ensuing accumulation of plastics and microplastics is likely to lead to increasing amounts of additives being leached to the environment with time (Barnes et al., 2009). The accumulation of discarded plastic or microplastics in the environment represents an unquantified future source of plastic additives to the environment.

3.2.1 Emission factors

When calculating emissions from plastics, directly measured values are preferred. However, these are rarely available, so generic emission factors often need to be used. These are described in the OECD ESD (OECD, 2009, OECD, 2019). They take account of the particle size and volatility associated with a specific lifecycle phase or process. During the manufacturing stage, particle size affects the loss of solids as dust or particulates with a threshold value of 40 µm. Volatile losses are related to the vapour pressure at the temperature of the process being considered. The wide range in the type of plastic materials, the processing methods used, the form of the product, the service conditions and the mode of disposal mean that average values may not be representative. Thus, all emission factors relate to worst case scenarios.

Emission factors describe the relationship between the amount of additive emitted from the material during a specific life stage with the amount present within the material and may be used to estimate the potential emission of additives on an individual basis for a specific lifecycle phase. Table 3-3 provides several emissions factors at key lifecycle stages; raw materials handling, compounding, conversion, service life and end-of-life for groups of additives under the key technical functions as identified in Section 2. Disposal emissions factors are modelled on current estimates for the main mechanisms for disposal of plastic waste in the United Kingdom (OECD, 2009). In general, emissions are greatest during service life of the article, although there is large variation between different additive functions and chemical properties, and the service life application (OECD, 2009).

Table 3-3. Emissions factors for each of the key technical functions as outlined in the ESD report (OECD, 2009).

			Additive loss at lifecycle stage, %					
Technical function of additive	**Physical form**	**Emission mechanism**	**Raw material handling**	**Comp-ounding**	**Conver-sion**	**Service life**	**Disposal**	**Notes**
Antistatic agents								
Antistatic agent - inorganic	Generally solid	Partial solubility in the polymer results in a high susceptibility to leaching.			2.5	0.01	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Losses given for powders of particle size <40µm as worst case, plus >40 µm which may form smaller particulates during handling and transport, as worst case. For smaller sites (<750 t plastic y^{-1} increase conversion releases by a factor of 10). Values given for combined air and water emission.
Antistatic agent - low volatility			0.8	0.051	0.01	0.5 per day		
Antistatic agent - medium volatility				0.055	0.05			
Antistatic agent - high volatility				0.075	0.25			
Antioxidants								
Antioxidants - low volatility	Powders or pellets	Deterioration by oxidation in air shortening service life.	0.6	0.001	0.01	outdoor 0.16% x service life (product years)	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Losses for conversion are for open process, foamed articles; lower losses for conversion for closed & partially open processes & solid articles. Factor of 10 increase for processing significantly above 10. Increase by a factor of 10 for small (<750 t plastic $year^{-1}$) sites. Values given for combined air and water emission.
Antioxidants - medium volatility				0.015	0.05			
Antioxidants - high volatility				0.035	0.25			
Blowing agents								
Blowing agents	Inorganic and organic compounds in the form of gases, solids and liquids	The wide range in characteristics results in a wide range of emission mechanisms	0.6	0.050	0	0	Additive considered destroyed.	Values for loss of agent are for chemical blowing agents with particle size <40 µm, plus >40 µm which may form smaller particulates during handling and transport, as worst case. Values given for combined air and water emission.
Nucleating agents	Fine suspended particles							
Fillers								
Fillers – particulate	Power		0.6	0.001	2.51	0.01	Emissions from volatilisation and leaching considered negligible.	Worst case values for purposes of first tier emissions assessment. See OECD (2009) ESD for further detail. Values given for combined air and water emission.
Fillers - fibrous	Fibres		0.01	0.06	10.01	0.01		
Flame retardants								
Flame retardants - low volatility	Generally solid	Loss by dust generation in handling or volatility in compounding.	0.8	0.051	0.02	outdoor 0.16% x service life	Worst case scenario would be the loss of all remaining in the	Organics: Losses during compounding given for open processes, foamed articles, as a worst case scenario. Inorganics: Losses at conversion given for grinding/machining.
Flame retardants - medium volatility				0.055	0.05			

Technical function of additive	Physical form	Emission mechanism	Additive loss at lifecycle stage, %					Notes
			Raw material handling	Comp-ounding	Conver-sion	Service life	Disposal	
Flame retardants - high volatility		Poly-halogenated molecules often have greater volatility compared to non-halogenated compounds of comparable molecular weight.		0.075	0.25	(product years)	plastic at disposal.	Both: Handling losses are for particle size <40 µm, plus >40 µm which may form smaller particulates during handling and transport, as worst-case scenario. Factor of 10 increase for processing significantly above 10. Increase by a factor of 10 for small (<750 t plastic year^{-1}) sites. Values given for combined air and water emission.
Flame retardants - inorganic				0.050	2.51	0.1% over service life		
Heat stabilisers								
Heat stabilisers. Non-volatile solids	Mostly solids, with some liquid forms. Acid acceptors such as inorganic heavy metal containing compounds, organic derivatives. They may be volatile or involatile.	This will depend on the chemical properties of the additive. Loss by dust during handling, volatilisation during compounding and conversion, leaching during service life and disposal.	0.8	0.06	2.51	0.1% over service life	Landfill: leaching losses to water, but very limited volatilisation. Incineration: organic compounds destroyed, some inorganic in ash for disposal as waste.	See OECD ESD for further detail. Worst case releases given for compounding (calendaring, blown film, spread coating). For small sites apply a x10 factor for conversion. Handling losses are for particle size <40 µm, plus >40 µm which may form smaller particulates during handling and transport, as worst-case scenario. Values given for combined air and water emission.
Heat stabilisers - volatile solids (low volatility group)				0.052	0.01	Outdoor: leaching = 0.16%; Volatilisation = 0.05 over whole service life.		
Heat stabilisers - volatile solids (medium volatility group)				0.055	0.0375			
Heat stabilisers - volatile solids (high volatility group)				0.075	0.25			
Heat stabilisers - plastisol (all volatility groups)				0.05				
Heat stabilisers - liquids			0.01	0.001				
Heat stabilisers - plastisol				0.01				
Light stabilisers								
Light stabilisers - low volatility	Solids with low molecular weight	Partially dissolved in the plastic	0.8	0.051	0.01	outdoor 0.16% x service life (product years)	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Handling losses given for powders of particle size <40 µm plus >40 µm which may form smaller particulates during handling and transport, as worst case. Values given for combined air and water emission.
Light stabilisers - medium volatility				0.055	0.05			
Light stabilsiers - high volatility				0.025	0.25			
Colourants								
Colourants - pigment agents	Mostly inorganic with some organic	Form a separate diverse phase in the plastic	0.60	0.064	2.51	Outdoor 0.16% x service life (product years)	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Lack of data on colourants so they are classified as similar to the low volatility plasticisers. Emissions for pigments from grinding/machining as worst case. All other pigment operations 0.01%. Lower values reported for dyes. For small sites (<750 tonnes plastic y^{-1}) increase by a factor of 10. Values given for combined air and water emission.
Colourants - dyes	Organic	Dissolve in the plastic		0.06	0.018			

Technical function of additive	Physical form	Emission mechanism	Additive loss at lifecycle stage, %: Raw material handling	Comp-ounding	Conver-sion	Service life	Disposal	Notes
Plasticisers								
Plasticisers - low volatility	Most are liquid, some are waxy solids	Not chemically bound to the polymer, thus, able to migrate to the surface of the matrix where losses may occur.	0.002	0.00	0.01	Outdoor 0.16% x service life (product years)	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Values given for calendaring, blown film & spread film (conversion). Emissions are lower for other methods and large sites. For small sites emission factors should be increased by a factor of 10 and further factor of 10 for high temperatures (>200°C). Losses from high, medium and low volatility plasticisers are expected to be at a ratio of 5:1:0.2. Values given for combined air and water emission.
Plasticisers - medium volatility			0.01	0.00	0.05			
Plasticisers - high volatility			0.05	0.00	0.25			
Slip promoters								
Slip promoters - inorganic	Generally waxy solids or powders	Dust generation during handling, particulate loss and volatilisation during heating under compounding or conversion. Partial solubility in the polymer results in a high susceptibility to leaching.	0.80		2.51	0.1% over service life of product	Worst case scenario would be the loss of all remaining in the plastic at disposal.	Handling losses given for powders of particle size <40 µm plus >40 µm which may form smaller particulates during handling and transport, as worst case. Release given for open process, foamed article as worst case scenario. For small sites increase by factor of 10. For the organic additives the service life emission factor, complete release was considered complete after 200 days. Values given for combined air and water emission.
Slip promoters – organic - low volatility				0.064	0.01	0.5% per day		
Slip promoters – organic - medium volatility				0.08	0.05	0.5% per day		
Slip promoters – organic - high volatility				0.16	0.25	0.5% per day		
Curing agents								
Curing agents - solid	Generally, a co-monomer rather than an additive		0.8	0.6	0	0	Additive considered destroyed.	Handling losses given for powders of particle size <40 µm plus >40 µm which may form smaller particulates during handling and transport, as worst case. Values given for combined air and water emission.
Curing agents – liquid			0.01	0.01	0	0		
Viscosity modifier								
Viscosity modifier	Suspended fine particles. High molecular weight polymer (different from PVC)	Low volatility due to high molecular weight. Leaching will be dependent on chemical properties.	0.8	0.06	0	0	Worst case scenario would be the loss of all remaining in the plastic at disposal, but this is unlikely to be released.	Handling losses given for powders of particle size <40 µm plus >40 µm which may form smaller particulates during handling and transport, as worst case. Values given for combined air and water emission.

4. Relative risk ranking exercise for PVC additives

A simple and conservative first-tier qualitative screen of the 228 substances considered to be relevant PVC additives for the UK was performed to generate a relative risk ranking. The aim was to identify which PVC additives are likely to pose the greatest risk to human health and the environment, to prioritise substances for further work.

This is a screening exercise rather than a formal risk assessment. Substances identified as a high priority should be subject to a more detailed quantitative risk assessment and/or collation of additional data to address critical evidence gaps.

4.1 The approach

A score of low, medium, or high was assigned to each substance for hazard and emission potential. These scores were then combined and used to determine an overall relative priority ranking. Full results from this exercise are provided in the technical appendix to this report. The scoring methods are described in the following sections.

4.1.1 Hazard score

For each of the 228 substances, data on biodegradation, bioaccumulation potential, environmental mobility and ecotoxicity were compiled together with human health CLP classifications of concern.

The criteria for a substance ranked as low hazard is defined, for this exercise, as one which shows no or low hazard to the environment or human health. This includes substances which fulfil any of (v)P, (v)B, M and/or T criteria but are not identified as, or under assessment for, PBT, PMT, vPvM, vPvB, or ED, nor show any human health CLP classifications of concern. The criteria used to assign P, B, T and M conclusions are detailed in Appendix 2 Table 11-1, while ED status was identified using ECHA's ED assessment list (ECHA, 2023).

A substance ranked as medium hazard was identified as potentially PBT, PMT, vPvM, vPvB, and/or ED, or is under regulatory assessment for any of these (e.g. included in the EU REACH Community Rolling Action Plan (CoRAP)), and/or possesses human health properties of concern, including respiratory and skin sensitisers (1, 1A, 1B), carcinogens (1, 1A, 1B), mutagens (1, 1A, 1B, 2), reprotoxins (1, 1A, 1B, Lact.) and specific target organ toxicants (1, 2). With regards to the CLP classifications, these were considered as part of the classification if they were harmonised, or in the case of self-classification, if most notifiers agreed.

High hazard substances were those that met the criteria for hazard classes PBT, PMT, vPvM, vPvB, and/or ED. Substances that have received regulatory scrutiny and are identified as substances of very high concern (SVHC) under EU REACH fell into this category but have been distinguished from substances meeting these criteria which have not yet received any regulatory scrutiny, since the intention of the work is to identify priorities for further work.

4.1.2 Emissions potential

The potential for emissions and thus exposure was scored by considering information on UK tonnage from UK REACH registrations together with key factors that influence the release potential of the additive from plastic.

As described in Section 3.2, several factors influence the release rate of additives from PVC. Consequently, for the purposes of a first-tier screen, only simple qualitative indicators of release have been used to categorise the potential for release as high, medium, or low. The key factors that influence release potential are shown in Table 4-1 and include the typical concentration of the additive in finished articles (C_art), the technical function of the additive itself (in relation to how it is incorporated into the polymer matrix) and physico-chemical properties. When information on more than one of these indicators was available, the matrix was used to determine a result.

As a generalisation, releases during service life of PVC articles are deemed to be greatest compared with emissions during manufacture, compounding or conversion (OECD, 2009) and this was the lifecycle stage considered in this risk screening exercise. The simple, qualitative approach taken for exposure negates the need for specific information on article use such as length of service life and indoor or outdoor use which is not readily available.

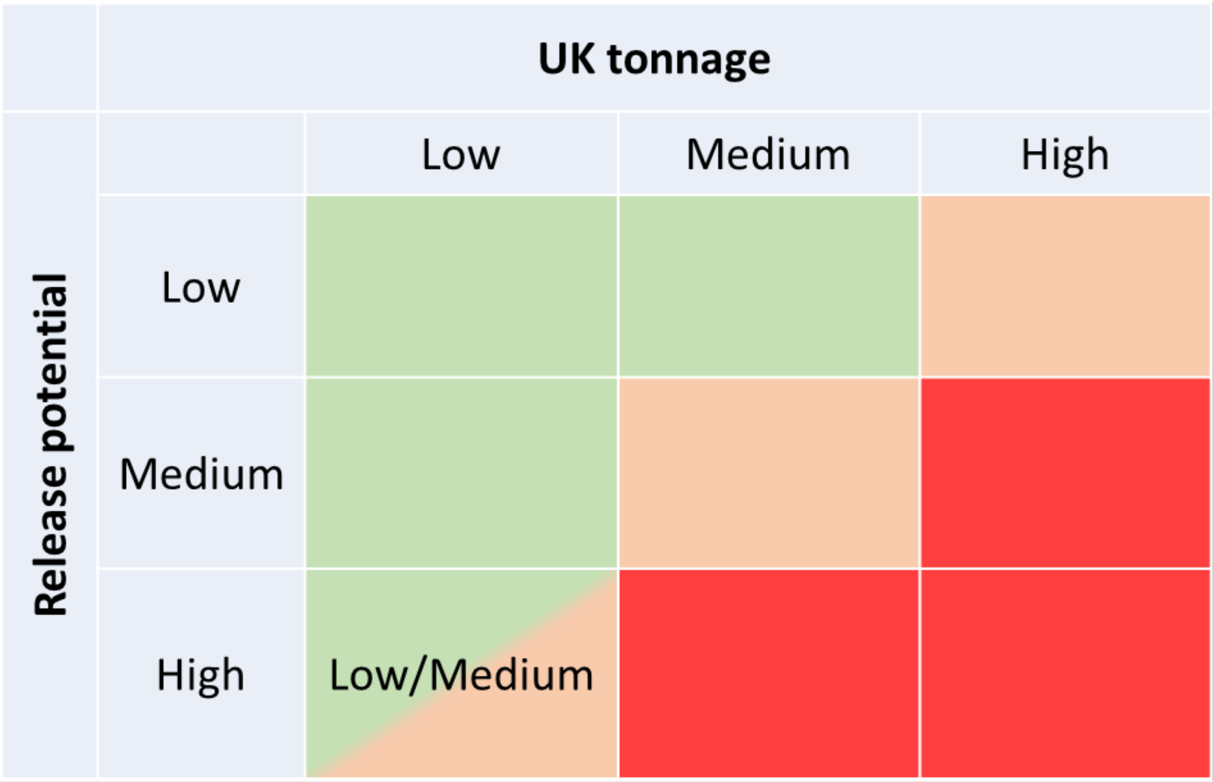
Tonnage and release potential were then combined (Figure 4-1) to give an overall score. If only part of this information was available, taking a conservative approach, the highest rank overall for the available data was used. For example, substances categorised as medium C_art but with no UK tonnage information were assigned a medium emissions potential score. Where both tonnage and C_art where available, the matrix as shown in Figure 4-1was used to determine the priority for that substance.

Table 4-1. Criteria for release potential used in the relative risk ranking exercise

Potential for release	Concentration in article	Nature of incorporation into the matrix	Physicochemical properties
Low	≤ 1%		High molecular weight (> 700) and K_{ow} > 7
Medium	> 1 to 10%		
High	> 10%	Slip promoters, anti-statics	

Those substances not currently registered under UK REACH and thus with no UK tonnage information have been marked as ND (no data). It is likely they are still used in articles imported into the UK and thus still have potential for release. The C_art was used in this instance to assess release potential.

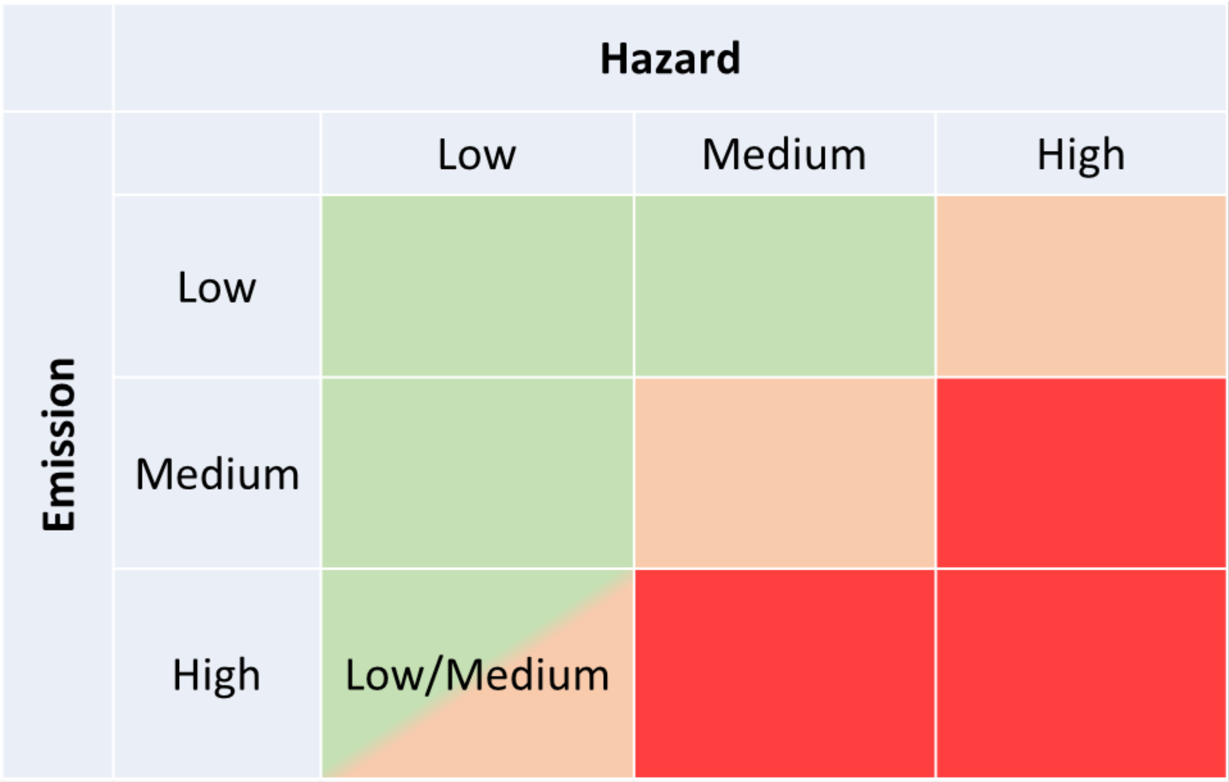
Figure 4-1. Scoring matrix for emissions potential, combining UK tonnage and release potential factors.



4.1.3 Overall score

A relative ranking was assigned using the matrix in Figure 4-2 to combine the hazard scores and emission scores for each substance. This gave a final rating of low, medium, or high for each of the 228 substances and allowed us to identify those which are of the highest priority for further scrutiny in the UK. Substances in the low/medium cell were assessed using expert judgement on a case-by-case basis.

Figure 4-2. Scoring matrix combining hazard and emissions to give an overall priority ranking



4.2 Relative release indicator (ECHA approach)

Much of the work on release of additives from PVC and other plastics has been concerned with the release of additives to food from plastic food contact materials (Brandsch et al., 2015). As part of their work, the ECHA-industry plastic additives initiative developed a methodology for comparing and ranking the relative release potential of additives from plastic matrices, including rigid and flexible PVC (ECHA, 2019) drawing on this body of research. They applied the relative release rankings generated as part of their mapping exercise to identify and prioritise which plastic additives should receive further regulatory scrutiny in the EU. The approach was applied to substances on their list which had not yet received regulatory scrutiny (58% of 418 substances) and fell within the applicability domain of the model, totalling 155 neutral organic components (ECHA, 2018b). Unfortunately, the outputs of the plastic additives initiative relative risk ranking are only available to EU Member State authorities and industry project partners and are not publicly available. We have therefore been unable to access their outputs to inform this project.

The method undertaken by ECHA is only applicable to neutral organic substances, as the behaviour of charged compounds is difficult to predict and there is currently no method applicable for inorganics (ECHA, 2019). Despite these limitations, we have explored the approach further to generate an additional, albeit limited, line of evidence to inform the prioritisation of additives for further study in the UK. The method for determining the relative potential for release is described in the supplementary material to ECHA's report (ECHA, 2019) and not repeated here in full but a brief summary is provided below. Only a limited number of substances (approximately 50) are within the applicability domain of the method so not all substances have been assigned a relative release indicator value.

The dermal release indicator was calculated for each substance according to ECHA (2019) and references therein. The ranking of the dermal route was considered by ECHA to also reflect well the ranking for other exposure routes (oral and the environment), and is the approach applied by the plastics initiative previously (ECHA, 2019).

The main input parameters required are: diffusion coefficient, log K_{ow}, and concentration of the additive in the article (ECHA, 2019). Diffusion coefficients for soft and rigid PVC were determined using the method described by the Joint Research Centre (JRC) (Brandsch et al., 2015). Log K_{ow} values for each additive have been taken from EU REACH registration dossiers and may differ from values used in the previous work by the plastics additives initiative where values were predicted using quantitative structure-activity relationships. A relative release indicator value for each substance, determined as the ratio of the release indicator to that of the substance with the greatest release indicator in the group was calculated to facilitate ranking of substances according to their relative release potential.

The relative release potential for additives used in rigid and flexible PVC respectively are included in Table 15-1 and Table 15-2 in Appendix 6. The substances for which a release indicator has been calculated are listed in order from greatest potential (rank 1) to lowest potential (rank ~ 50).

Our calculations of relative release potential are intended to inform our priority ranking exercise and to allow comparison between additives, but as the applicability domain is limited and many substances are excluded, they have limited value and have been used as an additional line of supporting evidence only. The following caveats must be noted when considering the information presented here. The release potential must not be confused with an exposure estimate. In addition, the relative release indicator does not consider hazard.

4.3 Results

Each of the 228 substances included in the scope of this project were assigned a risk ranking priority level of low, medium, or high using the approach in Section 4.1. Where insufficient data were available, substances were flagged as no data (ND). An overview of the substances assigned to each priority category, by technical functional category, as well as an overview of regulatory status is given in Table 4-2.

Table 4-2. Summary of data from the relative risk ranking exercise

Technical Function	Number of substances	EU REACH Registered	UK REACH Registered	Not registered under EU/UK REACH	Under evaluation on EU REACH CoRAP	Classified as SVHC	Subject to Risk Management Measures[1]	No regulatory scrutiny in the EU	Overall Relative Ranking Priority			
									High	Medium	Low	ND
Antistatic Agents	3	3	2	0	1	1	0	1	1	1	1	0
Antioxidants	8	8	7	0	1	0	0	7	0	3	5	0
Blowing Agents	1	1	1	0	0	1	0	0	0	1	0	0
Fillers	1	1	1	0	0	0	0	1	0	1	0	0
Flame Retardants	6	6	5	0	5	1	0	1	5	0	1	0
Heat Stabilisers	22	19	11	3	3	6	6	13	6	10	5	1
Light Stabilisers	7	7	3	0	2	1	0	5	0	2	5	0
Lubricants	9	9	6	0	0	0	0	9	0	2	7	0
Nucleating agents	1	1	0	0	0	0	0	1	0	0	1	0
Other Function	2	2	2	0	0	0	0	2	0	0	2	0
Other Stabilisers	2	2	2	0	0	0	0	2	0	0	2	0
Pigments	93	86	54	3	7	2	3	83	2	38	53	0
Plasticisers	71	58	39	13	12	7	11	48	12	7	45	7
Slip Promoters	1	1	1	0	0	0	0	1	1	0	0	0
Viscosity Modifiers	1	1	1	0	0	0	0	1	0	0	1	0

[1] Use either restricted under Annex 17 or requires authorisation under Annex 14 of UK or EU REACH.

Of the 228 PVC additives included in the scope of this project, 205 are registered under EU REACH and 135 are currently registered under UK REACH. Only 19 of the substances reviewed are not registered in either the UK or EU. 30 substances are subject to Substance Evaluation under EU REACH. 19 additives are already identified as SVHCs. The remaining 180 substances are not currently under any regulatory scrutiny in the EU.

4.3.1 Substances of concern

PVC additives used as antistatic agents, antioxidants, blowing agents, fillers, light stabilisers, lubricants, nucleating agents, “other function”, other stabilisers and viscosity modifiers were ranked medium or low priority based on their relative risk ranking. The flame retardants, heat stabilisers, pigments, plasticisers and slip promoter functional categories all contained at least one substance deemed to be of high relative risk. These substances and functional additive groups have been identified as the highest priority for further scrutiny of their potential risks to human health and the environment.

Table 4-3 lists the 27 substances that were assigned a high priority using the relative risk ranking method, along with their current regulatory status. Substances rated as medium priority can be found in Table 13-1 in Appendix 4.

Table 4-3. List of substances shown to be of highest priority based on the outcome of the relative risk ranking

CAS	Substance name	Functional category	Regulatory status in the UK and EU
1330-43-4	Disodium tetraborate, anhydrous	Antistatic agent	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2010) under UK REACH.
63449-39-8	Paraffin waxes and hydrocarbon waxes, chloro	Flame retardants	Undergoing Substance Evaluation under UK REACH due to suspected PBT properties (Health and Safety Executive, 2022).
68937-41-7	Phenol, isopropylated, phosphate (3:1)	Flame retardants	Substance included in the EU CoRAP (2020). Under assessment as PBT.
84852-53-9	1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene]	Flame retardants	Substance included in the EU CoRAP (2012). Under assessment as PBT.
85535-85-9	Alkanes, C14-17, chloro	Flame retardants	SVHC due to being PBT and vPvB. Included in the candidate list for authorisation under EU REACH (2021) but not UK REACH. UK nomination as a persistent organic pollutant under the United Nations Stockholm Convention.
97416-84-7	1,1'-(Isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene]	Flame retardants	Substance included in the EU CoRAP (2017). Under assessment as ED.
12065-90-6	Pentalead tetraoxide sulfate	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2012). Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
12202-17-4	Tetralead trioxide sulfate	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2012) under UK REACH. Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
12578-12-0	Dioxobis(stearato)trilead	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2012) under UK REACH. Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
15571-58-1	2-Ethylhexyl 10-ethyl-4,4-dioctyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2014) under UK REACH. The European commission established 2025 as the sunset date, but this does not apply under UK REACH. Some uses of this substance are restricted under Annex 17 of UK REACH.
62229-08-7	Sulfurous acid, lead salt, dibasic	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2012) under UK REACH The European

CAS	Substance name	Functional category	Regulatory status in the UK and EU
			commission established 2025 as the sunset date, but this does not apply under UK REACH. Some uses of this substance are restricted under Annex 17 of REACH.
91031-62-8	Fatty acids, C16-18, lead salts	Heat stabilisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2012) under UK REACH. Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
3896-11-5	Bumetrizole	Light stabilisers	Substance included in the EU Candidate List of SVHCs (2024) due to its vPvB properties.
1344-37-2	Lead sulfochromate yellow	Pigment agents	SVHC due to being carcinogenic and toxic to reproduction. Included in the candidate list for authorisation (2010) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
12656-85-8	Lead chromate molybdate sulfate red	Pigment agents	SVHC due to being carcinogenic and toxic to reproduction. Included in the candidate list for authorisation (2010) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
77-94-1	Tributyl citrate	Plasticisers	Under assessment in the EU as ED, though not on the EU CoRAP.
84-74-2	Dibutyl phthalate	Plasticisers	SVHC due to being toxic to reproduction and possessing endocrine disrupting properties (human health). Included in the candidate list for authorisation (2008) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some uses of this substance are restricted under Annex 17 of UK REACH (2016). Under assessment as PBT.
103-23-1	Bis(2-ethylhexyl) adipate	Plasticisers	Substance included in the EU CoRAP (2020).
117-81-7	Bis-(2-ethylhexyl) phthalate	Plasticisers	SVHC due to being toxic to reproduction and possessing endocrine disrupting properties (human health and environment). Included in the candidate list for authorisation (2008) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some

CAS	Substance name	Functional category	Regulatory status in the UK and EU
			uses of this substance are restricted under Annex 17 of UK REACH (2016).
3319-31-1	Tris(2-ethylhexyl) benzene-1,2,4-tricarboxylate	Plasticisers	Substance included in the EU CoRAP (2012). Under assessment as PBT and ED.
53306-54-0	Bis(2-propylheptyl) phthalate	Plasticisers	Substance included in the EU CoRAP (2020). Under assessment as ED.
3622-84-2	N-Butyl benzene sulfonamide	Plasticisers	None.
84-61-7	Dicyclohexyl phthalate	Plasticisers	SVHC due to being toxic to reproduction and possessing endocrine disrupting properties (human health). Included in the candidate list for authorisation (2018) under UK REACH.
84-75-3	Di-n-hexyl phthalate	Plasticisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2013) and in Annex 14 for authorisation under UK REACH (sunset date has passed).
131-18-0	Di-n-pentyl phthalate	Plasticisers	SVHC due to being toxic to reproduction. Included in the candidate list for authorisation (2013) and in Annex 14 for authorisation under UK REACH (sunset date has passed).
85-68-7	Benzyl butyl phthalate	Plasticisers	SVHC due to being toxic to reproduction and possessing endocrine disrupting properties (human health). Included in the candidate list for authorisation (2008) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
84-69-5	Diisobutyl phthalate	Plasticisers	SVHC due to being toxic to reproduction and possessing endocrine disrupting properties (human health). Included in the candidate list for authorisation (2008) and in Annex 14 for authorisation under UK REACH (sunset date has passed). Some uses of this substance are restricted under Annex 17 of UK REACH (2016).
10094-45-8	(Z)-N-Octadecyldocos-13-enamide	Slip promoter	None.

Of the 27 substances identified as being of the highest priority for further consideration, only 3 are not currently under formal regulatory scrutiny or risk management in either the UK or EU.

- Tributyl citrate (CAS 77-94-1) acts as a plasticiser in flexible PVC. It is under assessment in the EU as an endocrine disruptor and has a high release potential due to a high concentration present within articles (10-35% by weight) and a medium UK tonnage. Nevertheless, it is rapidly degradable and has a low bioaccumulation potential. Its relative priority for the environment may therefore be lower than suggested.

- N-Butyl benzene sulfonamide (CAS 3622-84-2) is also a plasticiser. The substance is potentially PMT and vPvM. There is no information on the concentration typically found in articles, but plasticisers are typically found in concentrations of up to 35% by weight in flexible PVC, indicating a potentially high likelihood of emission. The UK tonnage band for the chemical is high.

- (Z)-N-Octadecyldocos-13-enamide (CAS 10094-45-8) acts as a slip promoter. The substance is potentially PBT and vPvB. Slip promoters are generally considered to have a higher level of emissions due to the properties which allow their technical function. The typical concentration within articles is 5% by weight and there is a medium UK tonnage, indicating the possibility of emissions.

Substances which do not have sufficient data to be able to categorise their priority ranking are also worth noting. The substances listed in Table 4-4 have insufficient hazard data and an EU REACH tonnage band is unavailable, so it was not possible to determine their relative risk to human health and the environment. They are therefore identified as data deficient. Except for one substance which functions as a heat stabiliser, they are all plasticisers. Plasticisers are typically found in PVC at higher concentrations (up to 35% by weight) which suggests a higher potential for release from articles. 3 of the substances are polymers, so might be of lower importance than the others given their expected high molecular weights.

Table 4-4. Substances with a lack of data which should be flagged for further scrutiny

CAS	Substance name	Functional category
15647-08-2	2-Ethylhexyl diphenyl phosphite	Heat stabilisers
208945-13-5	Hexanedioic acid, polymer with 2,2-dimethyl-1,3-propanediol and 1,2-propanediol, isononyl ester	Plasticisers
82904-80-1	Hexanedioic acid, polymer with 1,2-propanediol, octyl ester	Plasticisers
55799-38-7	Hexanedioic acid, polymer with 1,2-propanediol, acetate	Plasticisers
91082-17-6	Alkylsulfonic acid ester with phenol	Plasticisers
68515-40-2	Benzyl C7-9-branched and linear alkyl phthalate	Plasticisers
146-50-9	Di-isohexyl phthalate	Plasticisers
131-16-8	Di-n-propyl phthalate	Plasticisers

4.3.2 Additive function priority ranking

Of the substances assessed as part of this project, the functional groups which pose the highest potential risk in the UK are flame retardants, heat stabilisers, pigments, plasticisers and slip promoters. Each of these has at least one substance determined to be high priority based on the outcome of the relative risk ranking exercise. Proportionally, this risk is higher for some functional groups than others. Five out of six flame retardants were ranked as high priority, six out of 22 heat stabilisers, two out of 93 pigments, 12 out of 71 plasticisers, and the only slip promoters studied in this project. Based on this, flame retardants, followed by heat stabilisers are the functional groups of greatest concern. This excludes slip promoters, as there was only one substance in this category, and so it cannot be determined if this level of higher potential hazard is representative of other slip promoters not included in the scope of this project.

As shown in Table 4-2, additional functional groups have substances which should be considered a medium priority in the UK. These substances should also be further evaluated through quantitative risk assessment to refine the prioritisation and identify substances of concern. The full list can be found in Appendix 1 and consists of substances found in the functional groups of antistatic agents, antioxidants, blowing agents, fillers, heat stabilisers, light stabilisers, lubricants, pigments and plasticisers. Of the total of 66 substances on this list, 46 of these are not currently subject to regulatory measures in the EU and could therefore logically be the focus for further work.

With regards to low priority substances, antistatic agents, antioxidants, flame retardants, heat stabilisers, light stabilisers, lubricants, nucleating agents, other function, other stabilisers, pigments, plasticisers and viscosity modifiers all have substances which fall into this category. Nucleating agents, other stabilisers, other function and viscosity modifiers only have substances which categorised as low priority and so can be considered a lower priority for any further action.

4.3.3 Comparison of relative risk ranking outcomes to potential release following ECHA's methodology

The outputs of the relative risk ranking approach outlined in Section 4.1 have been compared to the outputs of the relative release indicator approach following ECHA's methodology, as described in Section 4.2. Neither of these methods is preferable over the other since both have limitations. However, it is useful to note similarities and differences in the outcomes of these two approaches.

4.3.3.1 Rigid PVC

Based on the risk ranking exercise using emissions potential and hazard, none of the rigid PVC additives which were within the domain of ECHA's relative release indicator approach were highlighted as high priority. They were split across the low and medium categories. This is mainly attributable to low UK tonnage band or lack of UK REACH registration, which influenced the emissions likelihood of the substances. Most substances towards the top of the ranked release potential list were identified as medium risk using the relative risk ranking approach. Lower ranking substances using ECHA's approach were typically identified as low risk using the relative risk ranking approach, suggesting the two approaches provided broadly similar rank order. As there were no high-risk substances assessed using this approach, it is difficult to conclusively state that the approaches gave similar outputs.

4.3.3.2 Flexible PVC

The additives present in flexible PVC which were within the domain of ECHA's release indicator approach showed substances split across all priority levels based on the risk ranking approach. This does not necessarily mean that additives present in flexible PVC are more hazardous than those found in rigid PVC. The relative release potential approach was not applicable to all 228 substances and consequently only a subset has been compared, however there was little correlation in outcomes between the two methods. When comparing the outcomes from the two approaches, it is important to remember that the two approaches are not comparable and only one considers hazard as well as potential for release.

5. Occurrence of PVC additives in the aquatic environment, indoor dust, and humans

Monitoring data for PVC additives in surface water and groundwater, indoor dust, and humans in the UK have been collected using Environment Agency monitoring datasets and recent scientific literature. Owing to the limited reporting of such data for the UK in the scientific literature, the literature review was expanded to encompass data for European countries.

Despite broadening the literature review, no information could be found for many of the 228 substances considered in this project. A summary of data relevant to PVC additives in the UK that was found is provided below.

5.1 Environment Agency monitoring data for the aquatic environment in England

Publicly available water quality monitoring datasets for surface water and groundwater in England have been analysed to collate evidence on the presence of PVC additives relevant to the project. The Environment Agency data sources examined are summarised in the sections below.

5.1.1 Environment Agency semi-quantitative water quality monitoring data

Monitoring data are collected in English waters for a broad range of emerging contaminants by the Environment Agency for use in their Prioritisation and Early Warning System (PEWS) to identify contaminants of emerging concern. Two analytical screening methods are used: gas chromatography–mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS). The screening method is only semi-quantitative and any reported concentration data should be used with caution. In addition, sampling is not necessarily targeted at locations where concentrations might be highest. The data are most suitable for use as an indication of presence or absence only. Sampling regimes are spatially and temporally variable and data have been aggregated nationally.

In November 2022, the Environment Agency supplied summary data from their emerging contaminant targeted screen for 2018 to 2021. 18 substances used as plastic additives are reported. Data are reported separately for each analytical method (GC-MS and LC-MS) and surface water (freshwater) and groundwater in Table 5-1 to Table 5-4.

Of the 18 substances reported, 17 were detected using GC-MS (Table 5-1 and Table 5-2) and 3 were measured using the LC-MS method (Table 5-3 and Table 5-4). For each of the PVC additives monitored, data are presented as percent (%) detections, defined as the number of detections as a percent of total analyses, and as percent sites detected, defined as the number of sites detected as a percent of total sites analysed.

The numeric minimum, maximum and mean concentration values (µg/L) have been provided for completeness in Appendix 5, however these should be treated as indicative only, owing to the high degree of uncertainty associated with semi-quantitative data. Mean, median, and standard deviation values were provided by the Environment Agency and calculated using only data reported above the limit of detection (LOD) and when at least three values are present in a summary category.

The plasticiser and flame retardant triphenyl phosphate were the most frequently detected substance in both freshwater and groundwater samples each year, across both methods of detection, with GC-MS detections at 59% of freshwater sites (238 out of 404 sites) in 2018 and 68% of freshwater sites in 2021 (168 out of 248). Triphenyl phosphate was subject to a SEv under EU REACH for endocrine disruption (ED), prior to the UK leaving the EU. The plasticisers bis(2-ethylhexyl)adipate and bis-(2-ethylhexyl) phthalate were also detected relatively frequently at sites. Throughout the range of years, bis(2-ethylhexyl)adipate was detected at 10-54% of freshwater sites and 1-13% of groundwater sites, while bis-(2-ethylhexyl) phthalate was detected at 17-58% of freshwater sites and 8-16% of groundwater sites.

The frequency of detection of each of these substances is variable across the four years of data but appears to increase. This is surprising for bis-(2-ethylhexyl) phthalate, since it has been subject to risk management in the EU for several years so the market would be expected to be declining. It is also a Priority Hazardous Substance under water protection legislation (which explains why it is included in so many monitoring programmes). In contrast, the frequency of detection for other plasticiser substances, such as benzyl butyl phthalate and tributyl-O-acetyl citrate decreased. For example, between 2018 and 2021, detection of tributyl-O-acetyl citrate decreased from 5.4% to 3.2% in freshwater sites, and from 2.2% to 0% in groundwater sites. Meanwhile detection of 2-ethylhexyldiphenyl phosphate decreased from 19% to 12% (GC-MS) and from 31% to 13% (LC-MS) between 2018 and 2021 in freshwater but increased from 2% to 8% (GC-MS) and from 1% to 10% (LC-MS) in groundwater. Triphenyl phosphate detection frequency in groundwater also increased, quite significantly, with time from 1% in 2018 to 19% in 2020 (LC-MS) and from 10% in 2018 to 18% in 2021 (GC-MS). These changes could be due to temporal or spatial changes in sampling since the screening programme does not consistently monitor the same sites each year. It may also reflect changes in use pattern of additives over time.

The plasticisers di-n-hexyl phthalate, dicyclohexyl phthalate, di-n-octyl phthalate, diisobutyl phthalate and diallyl phthalate, on the other hand, were barely detected in groundwater or freshwater throughout the sampling campaigns. Di-n-pentyl phthalate, di-n-propyl phthalate, triacetin and triethyl citrate were not detected at all at any sites (both freshwater and groundwater) at any time point.

Freshwater generally had higher detection frequencies than groundwater. However, as the data have been aggregated from monitoring that has varied spatially and temporally each year it is not possible to comment further on overall trends in environmental levels.

5.1.2 Environment Agency Water Quality Archive data (WIMS)

The Environment Agency's Water Quality Archive (WIMS) data provides fully quantitative water quality measurements across 2018 to 2021. Data collected as part of this monitoring programme tend to be from locations sampled routinely (minimum of nine times per year, typically monthly) and are often data collected for statutory monitoring and reporting purposes. Waters sampled included freshwater (rivers/running surface waters and ponds/lakes/reservoir waters), estuarine waters and groundwater in England. Only 6 substances relevant to this project have reported environmental occurrences in the WIMS water quality archive. This may be due to the scope of the WIMS archive; data is collected primarily for statutory reporting requirements, typically focussing on known environmental contaminants rather than emerging contaminants. The substances were all plasticisers: benzyl butyl phthalate, bis-(2-ethylhexyl) phthalate, diethyl phthalate, di-n-octylphthalate, dibutyl phthalate, and dimethyl phthalate.

Data are presented here in Table 5-5 by year and waterbody type. The total number of samples, minimum and maximum concentration, and percentage of samples less than the limit of detection (LOD) are reported.

Table 5-1. Summary of PVC additives detected in UK freshwater per year between 2018 and 2021

Substance	CAS	Detection frequency							
		2018		2019		2020		2021	
		% Sites detected (Total sites analysed 404)	% Detections (Total analyses 2560)	% Sites detected (total sites analysed 388)	% Detections (Total analyses 2645)	% Sites detected (Total sites analysed 339)	% Detections (Total analyses 606)	% Sites detected (total sites analysed 248)	% Detections (Total analyses 1475)
2-Ethylhexyldiphenyl phosphate	1241-94-7	19.3%	4%	8.0%	2%	1.2%	0.8%	11.7%	2.4%
Benzyl butyl phthalate	85-68-7	3.0%	0.5%	11.1%	1.8%	1.2%	0.7%	0.4%	0.1%
Bis(2-ethylhexyl) adipate	103-23-1	10.4%	1.9%	28.9%	5.1%	13.6%	8.3%	53.6%	12.6%
Bis-(2-ethylhexyl) phthalate	117-81-7	50.2%	13.1%	49.0%	12.8%	17.4%	10.1%	57.7%	14.6%
Diallyl phthalate	131-17-9	0	0	0	0	0	0	0	0
Dibutyl phthalate	84-74-2	0.5%	0.1%	12.1%	2.0%	3.8%	2.2%	2.4%	0.4%
Dicyclohexyl phthalate	84-61-7	0.2%	0.04%	4.4%	0.6%	0.6%	0.3%	0	0
Diethyl phthalate	84-66-2	1.2%	0.2%	14.7%	2.5%	0	0	4.8%	0.8%
Dimethyl phthalate	131-11-3	21.8%	5.4%	34.3%	10.1%	10.6%	6.6%	24.2%	5.2%
Di-n-octyl phthalate	117-84-0	0	0	0	0	0	0	0	0
Di-n-pentyl phthalate	131-18-0	0	0	0	0	0	0	0	0
Di-n-propyl phthalate	131-16-8	0	0	0	0	0	0	0	0
Diisobutyl phthalate	84-69-5	0	0	1.8%	0.3%	0	0	0	0
Triacetin	102-76-1	0	0	0	0	0	0	0	0
Tributyl-O-acetyl citrate	77-90-7	5.4%	1.2%	3.9%	0.6%	2.4%	2.3%	3.2%	0.5%
Triethyl citrate	77-93-0	0	0	0	0	0	0	0	0
Triphenyl phosphate	115-86-6	58.9%	20.5%	53.4%	14.7%	20.1%	12.4%	67.7%	20.1%

Source data: Environment Agency, GC-MS water quality semi-quantitative monitoring screen

Table 5-2. Summary of PVC additives detected in UK groundwater per year between 2018 and 2021

Substance	CAS	Detection frequency							
		2018		2019		2020		2021	
		% Sites detected (Total sites analysed 1385)	% Detections (Total analyses 1445)	% Sites detected (total sites analysed 1206)	% Detections (Total analyses 1231)	% Sites detected (Total sites analysed 198)	% Detections (Total analyses 201)	% Sites detected (total sites analysed 61)	% Detections (Total analyses 61)
2-Ethylhexyldiphenyl phosphate	1241-94-7	1.8%	1.7%	2.0%	2.0%	9.6%	9.5%	8.2%	8.2%
Benzyl butyl phthalate	85-68-7	0.2%	0.2%	0.4%	0.4%	2.0%	2.0%	0	0
Bis(2-ethylhexyl) adipate	103-23-1	0.6%	0.6%	5.5%	5.4%	3.5%	3.5%	13.1%	13.1%
Bis-(2-ethylhexyl) phthalate	117-81-7	7.9%	7.5%	8.9%	8.7%	7.6%	7.5%	16.4%	16.4%
Diallyl phthalate	131-17-9	0	0	0.1%	0.1%	0.5%	0.5%	0	0
Dibutyl phthalate	84-74-2	0.4%	0.4%	1.7%	1.6%	2.5%	3.0%	0	0
Dicyclohexyl phthalate	84-61-7	0	0	0.2%	0.2%	0	0	0	0
Diethyl phthalate	84-66-2	0.6%	0.6%	0.9%	0.9%	0	0	0	0
Dimethyl phthalate	131-11-3	2.3%	2.3%	3.0%	2.9%	2.0%	2.0 %	1.6%	1.6%
Di-n-octyl phthalate	117-84-0	0	0	0.1%	0.1%	0	0	0	0
Di-n-pentyl phthalate	131-18-0	0	0	0	0	0	0	0	0
Di-n-propyl phthalate	131-16-8	0	0	0	0	0	0	0	0
Diisobutyl phthalate	84-69-5	0.3%	0.3%	2.0%	2.0%	1.0%	1.0%	0	0
Triacetin	102-76-1	0	0	0	0	0	0	0	0
Tributyl-O-acetyl citrate	77-90-7	2.2%	2.1%	0.8%	0.8%	1.5%	1.5%	0	0
Triethyl citrate	77-93-0	0	0	0	0	0	0	0	0
Triphenyl phosphate	115-86-6	10.0%	9.6%	6.2%	6.1%	10.1%	10.0%	18.0%	18.0%

Source data: Environment Agency, GC-MS water quality semi-quantitative monitoring screen

Table 5-3. Summary of PVC additives detected in UK freshwater per year between 2018 and 2021

Substance	CAS	Detection frequency							
		2018		2019		2020		2021	
		% Sites detected (Total sites analysed 26)	% Detections (Total analyses 675)	% Sites detected (total sites analysed 106)	% Detections (Total analyses 413)	% Sites detected (Total sites analysed 23)	% Detections (Total analyses 116)	% Sites detected (total sites analysed 23)	% Detections (Total analyses 380)
2-Ethylhexyldiphenyl phosphate	1241-94-7	30.8%	2.1%	3.8%	1.5%	21.7%	6.0%	13%	1.1%
Di-n-hexyl phthalate	84-75-3	7.7%	0.3%	0.9%	0.2%	0	0	0	0
Triphenyl phosphate	115-86-6	11.8%	1.5%	33.0%	16.0%	26.1%	6.0%	26.1%	2.9%

Source data: Environment Agency, LC-MS water quality semi-quantitative monitoring screen

Table 5-4. Summary of PVC additives detected in UK groundwater per year between 2018 and 2021

Substance	CAS	Detection frequency							
		2018		2019		2020		2021	
		% Sites detected (Total sites analysed 356)	% Detections (Total analyses 369)	% Sites detected (total sites analysed 187)	% Detections (Total analyses 216)	% Sites detected (Total sites analysed 89)	% Detections (Total analyses 91)	% Sites detected (total sites analysed 21)	% Detections (Total analyses 21)
2-Ethylhexyldiphenyl phosphate	1241-94-7	1.4%	1.4%	2.1%	6.0%	3.4%	3.3%	9.5%	9.5%
Di-n-hexyl phthalate	84-75-3	0	0	1.1%	0.9%	0	0	0	0
Triphenyl phosphate	115-86-6	1.0%	1.0%	4.3%	6.0%	16.9%	18.7%		

Source data: Environment Agency, LC-MS water quality semi-quantitative monitoring screen

Table 5-5. Summary of PVC additives detected in English waters per year between 2018 and 2021

Substance	CAS number	Year	No. of samples	Minimum concentration (µg/L)	Maximum concentration (µg/L)	% samples < Limit of Detection
Freshwater						
Bis-(2-ethylhexyl) phthalate	117-81-7	2018	189	<0.2	1.85	62
Bis-(2-ethylhexyl) phthalate	117-81-7	2019	72	<0.2	1.03	63
Bis-(2-ethylhexyl) phthalate	117-81-7	2020	12	<0.2	<0.2	100
Bis-(2-ethylhexyl) phthalate	117-81-7	2021	890	<0.2	7.6	91
Estuarine water						
Bis-(2-ethylhexyl) phthalate	117-81-7	2018	25	<0.2	0.29	84
Groundwater						
Benzyl butyl phthalate	85-68-7	2018	2	<2	<2	100
Diethyl phthalate	84-66-2	2018	2	<1	<1	100
Di-n-octylphthalate	117-84-0	2018	1	<2	<2	100
Dibutyl phthalate	84-74-2	2018	1	<1	<1	100
Dimethyl phthalate	131-11-3	2018	1	<1	<1	100

Source data: Environment Agency Water Quality archive (WIMS)

Bis-(2-ethylhexyl) phthalate was detected at the highest concentration of any of the six PVC additives investigated, at a maximum concentration of 7.6 µg/L in freshwater in 2021 (Table 5-5). However, 91% of samples for bis-(2-ethylhexyl) phthalate in freshwater in 2021 were below the LOD, and those above the LOD were mostly below 1 µg/L. For samples detected above the LOD, freshwater concentrations of bis-(2-ethylhexyl) phthalate ranged from 0.2-1.9 µg/L in 2018, 0.2-1.0 µg/L in 2019, and 0.2-7.6 µg/L in 2021, while estuarine water concentrations ranged from 0.2-0.3 µg/L in 2018. Bis-(2-ethylhexyl) phthalate was not detected in groundwater. Five other phthalates were sampled across one or two groundwater sites, but all samples were detected at less than LOD. When looking at the dataset as whole, across all substances, environmental media and years, a large proportion (62 to 100%) of the samples were measured at less than the LOD.

5.2 Summary of Environment Agency monitoring data

Six high-priority substances were identified from the Environment Agency data, with five of these identified through the LC-MS or GC-MS semi-quantitative monitoring screen and three identified through the water quality archive (WIMS). These plasticiser additives are identified as being high-risk and are SVHCs due to their toxicity and endocrine disrupting properties. Among these high-priority substances, dibutyl phthalate, which was detected in both freshwater and groundwater, is currently under assessment as PBT.

5.3 Literature search

A systematic search of the scientific literature was conducted to compile evidence on the presence of PVC additives in different media across the UK and Europe. Monitoring data for surface waters and groundwater were collected to supplement the data provided by the Environment Agency, and data related to indoor dust and human biomonitoring samples were collected to investigate the reported presence of PVC additives across a wider range of sampling media.

Two bibliographic databases were accessed in January 2023 to conduct the searches: PubMed and Science Direct. The scientific papers on PubMed were searched using the USEPA Abstract Sifter (v6.1), a Microsoft Excel® based application. As Science Direct was returning many hits, the search was limited to literature published from 2010 onwards, although some pre-2010 data were extracted from review articles published after this time. Only the first 300 search results were reviewed in Science Direct as there were no relevant titles returned after the first 100 hits.

Owing to the large number of PVC additives, it was not feasible to search for data on a substance-by-substance basis. Therefore, generic search terms related to PVC additives, such as “PVC additive” and “polyvinyl chloride additive”, their functional groups, such as “phosphate” and “phthalate”, and their functions, such as “pigment” and “flame retardant”, were included in the search queries to find relevant results. The search queries used, and their number of hits can be found in Appendix 5 in Table 14-1.

5.3.1 PVC additives detected in the UK and Europe as reported in the scientific literature

Monitoring data for the UK found in the scientific literature are reported in Table 5-6. An equivalent table for European data can be found in Appendix 5. UK data were found for 9 plasticisers and 1 flame retardant, while European data were found for 18 plasticisers and 1 flame retardant.

5.3.1.1 Surface and ground waters

UK occurrence was only reported for 5 of the substances, all in England (bis-(2-ethylhexyl) phthalate; dibutyl phthalate; diethyl phthalate; dimethyl phthalate; tris(phenyl) phosphate). Most reports were for groundwater, with one in riverine surface water (triphenyl phosphate) (Cristale et al., 2013b, Lapworth et al., 2015). Lapworth et al. (2015) used the Environment Agency's semi-quantitative GS-MS screening dataset from 2011. There were no reported occurrences in Northern Ireland, Scotland, or Wales. Of the four substances reported in groundwater, concentrations ranging from 0.1 µg/L (dimethyl phthalate) to 2 µg/L (bis-(2-ethylhexyl) phthalate) (Lapworth et al., 2015). The reported concentration of triphenyl phosphate in the River Aire, Yorkshire, was lower at 0.015 µg/L (0.006-0.022 µg/L) (Cristale et al., 2013b).

The UK groundwater concentrations reported in the literature are similar to those reported in the Environment Agency's WIMS archive: the concentrations in WIMS were reported as <1 µg/L for dibutyl phthalate, diethyl phthalate and dimethyl phthalate, corresponding to values of 1.0, 1.3 and 0.1 µg/L in the literature, respectively (Lapworth et al., 2015). No WIMS data were available for bis-(2-ethylhexyl) phthalate in groundwater or for tris(phenyl) phosphate in surface waters. Substances that were detected in WIMS monitoring but not in the scientific literature for the UK include benzyl butyl phthalate and di-n-octylphthalate. However, these two substances were mentioned in the scientific literature when the search was expanded to include European samples, as was tris(2-ethylhexyl) phosphate.

Across Europe and the UK, the substance detected at the highest median concentration was bis-(2-ethylhexyl) phthalate, at 8.9 µg/L in a French river (Net et al., 2014). Dibutyl phthalate was recorded at the second highest concentrations, at 6.8 µg/L in Swedish surface water (Bastos and Haglund, 2012), 3.7 µg/L in Polish groundwater (Kotowska et al., 2020), and 2.1 µg/L in French river water (Net et al., 2014).

5.3.1.2 Indoor dust

Concentrations of PVC additives reported in indoor dust samples collected inside houses, offices, classrooms/day care centres and cars were collated. Four PVC additives were reported in indoor dust in the UK: the flame retardant/plasticiser tris(phenyl) phosphate, the flame retardant/plasticiser tris(2-ethylhexyl) phosphate, the flame retardant/plasticiser 2-ethylhexyl diphenyl phosphate and the flame retardant 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]. All samples were from England (Birmingham, Reading and West Midlands), with no reported occurrences found in the literature for Northern Ireland, Scotland or Wales. Median concentrations ranged from 0.1-1.1 µg/g for 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] (Ali et al., 2011, Kademoglou et al., 2017, Drage et al., 2020), 0.16 µg/g for tris(2-ethylhexyl) phosphate (Kademoglou et al., 2017), 1.5-4.3 µg/g for tris(phenyl) phosphate (Brommer and Harrad, 2015, Kademoglou et al., 2017), and 1.6-29 µg/g for 2-ethylhexyl diphenyl phosphate (Brommer and Harrad, 2015, Kademoglou et al., 2017).

When expanding the literature search to include European samples, the number of PVC additives detected increased from 4 to 18. There were reports of more phthalates, as well as plasticisers including adipates (e.g., dibutyl adipate), sebacates (e.g., dibutyl sebacate) and citrates (e.g., tributyl-O-acetyl citrate). In European dust samples, phthalates occurred at the highest levels, with diisononylphthalate, bis-(2-ethylhexyl) phthalate, and dioctyl terephthalate all reported at median concentrations of greater than 100 µg/g (Christia et al., 2019). The highest concentrations reported were for diisononylphthalate in dust in Swedish offices and a day care centre, with median concentrations above 200 µg/g and highest sample concentrations reaching 1,872 µg/g (Christia et al., 2019). Christia et al (2019) also reported median concentrations of 200 µg/g, ranging from 40-1,957 µg/g, for bis-(2-ethylhexyl) phthalate (Christia et al., 2019).

The same four substances detected in the UK were also detected in Belgium, Norway and Ireland (1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]); Norway and the Netherlands (2-ethylhexyl diphenyl phosphate); Norway (tris(2-ethylhexyl) phosphate); and Germany, the Netherlands, Norway and Romania (tris(phenyl) phosphate). European dust concentrations of 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene] ranged from 0.15-10 µg/g, similar to the 0.1-1.1 µg/g reported in England (Ali et al., 2011, Kademoglou et al., 2017, Wemken et al., 2019). Average concentrations of tris(2-ethylhexyl) phosphate and tris(phenyl) phosphate in Europe (0.18 and 0.36-7.5 µg/g, respectively) were also comparable to their reported levels in England (0.16 and 1.5-4.3 µg/g, respectively) (Brommer et al., 2012, Dirtu et al., 2012, Brandsma et al., 2014, Cequier et al., 2014, Fromme et al., 2014, Kademoglou et al., 2017, Sugeng et al., 2017). Average concentrations of the flame retardant and plasticiser 2-ethylhexyl diphenyl phosphate were an order of magnitude lower in Europe compared with levels reported for England, at 0.2-2.3 µg/g compared to 1.6-29 µg/g (Brandsma et al., 2014, Cequier et al., 2014, Kademoglou et al., 2017). This may be expected as the UK has stricter fire safety regulations and thus a higher reliance on flame retardants (Pemberton et al., 2022).

5.3.1.3 Human biomonitoring

For human biomonitoring samples in the UK, only reports of metabolites in urine samples were found in the scientific literature (Bevan et al., 2013, Exley et al., 2015, Haug et al., 2018).These were for the metabolites of: benzyl butyl phthalate (MBzP), bis-(2-ethylhexyl) phthalate (MEHP, MEHHP, MEOP, MEOHP), dibutyl phthalate (MnBP), diethyl phthalate (MEP), and diisobutyl phthalate (MiBP). Bevan et al. (2013), reported concentrations for bis-(2-ethylhexyl) phthalate metabolites, sampled every country if the UK, whilst Exley et al. (2015) and Haug et al. (2018) only reported data from English samples.

The metabolite of benzyl butyl phthalate was detected at least an order of magnitude lower (2.71 to 3.5 µg/g creatinine) than the metabolites of dibutyl phthalate (12.9 to 25.6 µg/g creatinine), diethyl phthalate (15.9 to182 µg/g creatinine), diisobutyl phthalate (16.3 to 28.7 µg/g creatinine), and bis-(2-ethylhexyl) phthalate (1.1- 22.7 µg/g creatinine) (Exley et al., 2015, Haug et al., 2018). Bevan et al. (2013) also reported values of 42.3-66.5 µg/g creatinine for bis-(2-ethylhexyl) phthalate, although these were derived from 95th percentile values rather than averages.

Table 5-6. Summary of PVC additives detected in surface and ground waters, indoor dust, and humans in the UK reported in the scientific literature

Substance	Media	Concentration[1]		Location	References
		Median	Range		
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene]	Indoor dust	1.1	0.5-39.2	West Midlands	(Kademoglou et al., 2017)
		0.66	<0.05-7.8	Birmingham	(Drage et al., 2020)
		0.1	<0.02-2.5	Reading	(Ali et al., 2011)
2-Ethylhexyl diphenyl phosphate	Indoor dust	2.2	0.29-11	West Midlands	(Brommer and Harrad, 2015)
		1.6	0.18-130	West Midlands	(Brommer and Harrad, 2015)
		5.3	0.15-81	West Midlands	(Brommer and Harrad, 2015)
		29	0.3-470	West Midlands	(Brommer and Harrad, 2015)
		2.4	0.3-9.2	Reading	(Kademoglou et al., 2017)
Benzyl butyl phthalate	Urine[2]	3.5		Bradford	(Haug et al., 2018)
		2.7		Bradford	(Haug et al., 2018)
Bis-(2-ethylhexyl) phthalate	Groundwater	1.5		Chalk aquifer-England	(Lapworth et al., 2015)
	Urine[2]	66.5[2]		England, Scotland, Wales, Northern Ireland	(Bevan et al., 2013)
		42.3[2]		England, Scotland, Wales, Northern Ireland	(Bevan et al., 2013)
		3.7		Bradford	(Haug et al., 2018)
		3.1		Bradford	(Haug et al., 2018)
		9.2		Bradford	(Haug et al., 2018)
		22.7		Bradford	(Haug et al., 2018)
		8.4		Bradford	(Haug et al., 2018)
		12.8		Bradford	(Haug et al., 2018)
		1.58[3]		England	(Exley et al., 2015)

[2] Value derived from 95th percentile value.

[3] Value is a geometric mean.

Substance	Media	Concentration[1] Median	Range	Location	References
		1.11[3]		England	(Exley et al., 2015)
		12.7[3]		England	(Exley et al., 2015)
		4.9[3]		England	(Exley et al., 2015)
		20.4[3]		England	(Exley et al., 2015)
		8.2[3]		England	(Exley et al., 2015)
Dibutyl phthalate	Groundwater	1.0		Chalk aquifer-England	(Lapworth et al., 2015)
	Urine[2]	22.7		Bradford	(Haug et al., 2018)
		25.6		Bradford	(Haug et al., 2018)
		25.2[3]		England	(Exley et al., 2015)
		12.9[4]		England	(Exley et al., 2015)
Diethyl phthalate	Groundwater	1.3		Chalk aquifer-England	(Lapworth et al., 2015)
	Urine[2]	182		Bradford	(Haug et al., 2018)
		46.4		Bradford	(Haug et al., 2018)
		15.9[4]		England	(Exley et al., 2015)
		25.6[4]		England	(Exley et al., 2015)
Diisobutyl phthalate	Urine[2]	37.2		Bradford	(Haug et al., 2018)
		63.8		Bradford	(Haug et al., 2018)
		28.7[4]		England	(Exley et al., 2015)
		16.3[4]		England	(Exley et al., 2015)
Dimethyl phthalate	Groundwater	0.1		Chalk aquifer-England	(Lapworth et al., 2015)
Tris(2-ethylhexyl) phosphate	Indoor dust	0.16	0.96-0.47	Reading	(Kademoglou et al., 2017)
Tris(phenyl) phosphate	Indoor dust	3.3	0.27-170	West Midlands	(Brommer and Harrad, 2015)
		3.3	0.49-110	West Midlands	(Brommer and Harrad, 2015)
		4.3	0.56-50	West Midlands	(Brommer and Harrad, 2015)
		4.1	0.22-90	West Midlands	(Brommer and Harrad, 2015)
		1.5	0.19-9.6	Reading	(Kademoglou et al., 2017)
	Surface water	0.015	0.01-0.02	River Aire-Yorkshire	(Cristale et al., 2013b)

Note: 1 - Units: dust = µg/g; urine = µg/g creatinine; water = µg/L.

2 - For urine samples, the metabolites of the PVC additive substances were reported.

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[4] Value is a geometric mean.

Human biomonitoring data reported in the literature for Europe encompassed a much wider range of sample matrices, including nails, breast milk and serum in addition to urine. The same substances were reported as for the UK, with the addition of diphenyl phosphate in urine (van der Schyff et al., 2023), and the dimethyl phthalate metabolite, MMP, which was reported in urine (Koch et al., 2003, Högberg et al., 2008, Ye et al., 2009, Koch et al., 2017), breast milk (Main et al., 2006) and nails (Giovanoulis et al., 2016). Long chain chlorinated paraffins (LCCPs), which incorporates the substance paraffin waxes and hydrocarbon waxes, chloro, has also been found in human milk (Zhou et al., 2020).

Concentrations of plastic additives in urine from samples across Europe were consistent with patterns reported for England, that is, from highest to lowest average concentrations:

- diethyl phthalate (12.1-310 µg/L (Ye et al., 2009, Völkel et al., 2014));
- dibutyl phthalate (8-111 µg/L (Koch et al., 2003, Koch et al., 2017)) and diisobutyl phthalate (9.8-103.9 µg/L (Kasper-Sonnenberg et al., 2012, Koch et al., 2017)) and bis-(2-ethylhexyl) phthalate (1.1-174.6 µg/L (Becker et al., 2009, Völkel et al., 2014));
- benzyl butyl phthalate (3.1-5.4 µg/g creatinine (Cullen et al., 2017)).

Serum concentrations were consistently amongst the lowest reported concentrations for the PVC additive metabolites (0.5 µg/L in Sweden for diisobutyl phthalate, dibutyl phthalate, diethyl phthalate and bis-(2-ethylhexyl) phthalate (Högberg et al., 2008)), while nail concentrations were amongst the highest (Alves et al., 2016, Giovanoulis et al., 2016).

5.4 Summary of literature search findings

Of the PVC additive detections reported in the literature, four substances were categorised as high priority (Table 5-6). 1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene], a flame retardant under PBT assessment, was detected in indoor dust, although it should be noted that it is widely used in a variety of applications beyond PVC. The plasticiser benzyl butyl pthalate was detected in urine and a further two plasticisers, bis-(2-ethylhexyl) phthalate and dibutyl phthalat were detected in urine and groundwater. These plasticisers are all SVHCs due to their reproductive and endocrine disrupting properties and some uses of these additives are restricted under Annex 17 of UK REACH (2016).

Alongside these high-priority substances, 2-ethylhexyl diphenyl phosphate was detected in multiple studies in indoor dust. This heat stabiliser has been identified as needing further scrutiny because of insufficient hazard data and no information on tonnage. Its detection could highlight it as a substance to include in future monitoring programmes.

6. Recent changes in the PVC market

As described in previous sections, globally, PVC represents one of the most widely used polymers, testament to its versatility across a range of industrial, technical and everyday applications. The UK is a global leader in the plastics industry, with an annual sales turnover of £27 billion, employing approximately 162,000 workers across 5,800 companies. Plastics are the second largest employer in the UK manufacturing sector, with plastics being in the top 10 of the UK's exports (British Plastics Federation, 2021). Nevertheless, there is a general trend in goods manufacturing, such as electrical devices, moving away from the UK and Europe to countries where the implementation of international chemical agreements may differ fundamentally from the UK (EA, pers. comm).

6.1 Changes in the UK

Between 2017 and 2019 there was a 71% decline in PVC packaging (grocery and non-grocery retail) in the consumer sector in the UK, down to an estimated 7 kilotons in 2019. This represented the largest change to packaging in the UK consumer sector. This was likely to be a result of UK Plastics Pact which was launched in 2018. The pact aims to eliminate all problematic and unnecessary plastic packaging by 2025, including PVC packaging used in films, pots, tubs and trays. The PVC placed on the market in the non-consumer sectors such as commercial and industrial over the same time period remained unchanged (WRAP, 2021). In January 2023, the UK government made a further move towards this, announcing a ban on a range of single-use plastics across England would come into place in October 2023, which is likely to have the most impact on the hospitality sector.

PVC recycling in the UK is continually increasing, with the UK and Ireland collecting and recycling 143,428 tonnes of waste PVC in 2019 across all PVC recycling formats – this represents 18.6% of all waste PVC which was recycled throughout Europe in 2019 (second only to Germany), and was an increase of 4.3% based on the previous year (British Plastics Federation, 2020).

6.2 EU versus UK market changes

The PVC industry in Europe had a difficult 2022, with rising gas and electricity prices resulting in higher production costs, leading to a gradual decline in demand and thus creating uncertainty over the long-term growth of the PVC market. Talks are underway in the EU regarding price caps for natural gas, which could help to regulate prices. However, at present EU Member States are debating the cost-effectiveness of PVC production – particularly when imports into Europe from the United States of America, Turkey, Egypt, South Korea and southeast Asia are more competitively priced (Argus Media, 2022). In the

UK, a similar effect was observed, with increased costs due to energy prices, and with these costs anticipated to keep rising over time (Plastics Information Europe, 2022).

Controls under the United Nations Stockholm Convention on Persistent Organic Pollutants (POPs) and recent EU REACH restrictions of substances in PVC (such as lead compounds – see Section 6.4) could make PVC recycling uneconomic, resulting in the potential collapse of the EU recycling sector. It is uncertain whether this will affect all PVC recycling or certain types only, but flexible PVC cables are most likely to be affected. Since the UK does not have the same restrictions in place, this could lead to an increase in imports of PVC waste from the EU into the UK (EA, pers. comm).

6.3 Market resilience

Whilst plastic is indispensable in almost every sector and although production appears resilient in its growth, the market remains susceptible to perturbation caused by external factors. An important example of this may be observed in the effects of COVID-19 pandemic and lockdown measures of 2020, which were observed globally as having a significant impact on plastic production, use and waste. In most sectors, plastics use reduced in line with the reduction in demand and output (2.2% decrease), however, this was sector specific as plastic use in healthcare increased significantly (OECD, 2022).

The pandemic also resulted in disruption to plastics recycling. This may be attributed to the halting of some work within the plastics recycling trade and the reduction in the price of oil resulting in low prices for primary plastics. A switch to greater use of single-use plastics placing greater pressure on waste disposal processes also served to exacerbate issues relating to plastic littering on land and in marine environments (Ebnera and Iacovidou, 2021).

6.4 PVC additives of concern

Both the UK and the EU implement the United Nations Stockholm Convention on Persistent Organic Pollutants (POPs), although concentration limits may differ (for example, the EU has recently reduced its concentration limits for polybromodiphenyl ethers (PBDEs) and short-chain chlorinated paraffins (SCCPs)). If the POP content of waste material is at or above the listed concentration limits, the waste is known as POPs waste. The legislation requires rigorous control of POPs waste, including the destruction or irreversible transformation of the POPs in POPs waste. All reasonable steps must be taken to avoid mixing POPs waste with other waste during storage, collection and treatment. Where waste is mixed, the whole load must be managed as POPs waste. The POPs content must be destroyed/transformed even if the mixing has diluted the POPs to below the concentration limit. However, there is evidence that some types of PVC product (such as cabling used in electrical devices) produced outside of the UK and Europe might continue to contain substances that are controlled as POPs (particularly decabromodiphenyl ether (decaBDE) and chlorinated paraffins that contain a fraction that is equivalent to SCCPs). The recent agreement to identify medium-chain chlorinated paraffins (MCCPs) as a POP will also affect some types of PVC once it is added to one of the annexes of the Stockholm Convention (EA, pers. comm).

In addition, much of the PVC consumed in the UK is currently manufactured in countries outside Europe that are yet to implement the Stockholm convention. Consequently, non-compliant products are suspected to be commonplace on both the UK and EU markets (EA, pers. comm).

Other additives of concern are phthalic acid esters (phthalates), used as plasticisers. Many of the more harmful phthalates that were once widely used in PVC (e.g. bis-(2-ethylhexyl) phthalate) are subject to restrictions and authorisation under both UK and EU REACH (ECHA, 2016b). Alternatives to these plasticisers with similar functions include citrates, benzoates, aliphatic esters and bio-based compounds (Turner and Filella, 2021, Stieger, 2015, European Parliament, 2015).

Cadmium- and lead-based primary thermal stabilisers were traditionally used to prevent dehalogenation and to neutralise hydrochloric acid.

- Cadmium-based stabilisers were used for many years due to excellent performance qualities including weatherability, almost invariably combined with a barium ester. Although naturally occurring, there were concerns about the effects that higher concentrations of cadmium in PVC dust could have on the environment and human health, due to its toxicity and possible accumulation in the body. Cadmium compounds are now subject to restriction under both UK and EU REACH (ECHA, 2016a). In products such as roofing membranes and window profiles, cadmium stabilisers have been replaced with barium/zinc stabilisers (VinylPlus, 2014).

- Lead compounds have been used as a PVC stabiliser for many years due to their cost effectiveness and long-term stabilisation properties. The intentional introduction of lead compounds into PVC was voluntarily phased out by European producers due to concerns over the adverse health effects of lead present in PVC dusts. Lead is still used in PVC articles produced outside the EU, so a restriction was subsequently adopted under EU (but not UK) REACH (ECHA, 2016c). Calcium-based stabilisers are used as a substitute (VinylPlus, 2014).

Less hazardous metal-based stabilisers are still used in PVC, including the salts of barium, zinc and organotin compounds, however efforts are ongoing to replace all metal compounds with organophosphites (Turner and Filella, 2021).

6.5 Secondary plastics markets

Alongside other plastic waste reduction strategies, recycling has an important role to play in lowering the environmental impact of plastics. Recycling plastics can help to reduce demand for primary (virgin) plastics and also divert plastic material away from other, more harmful waste disposal options (OECD, 2022). However, it is uncertain whether other disposal options are more harmful than recycling for flexible PVC that contain heavy metals, phthalates and POPs.

Whilst the rate of secondary plastic production has increased over the last 20 years, it still only accounts for 6% of total plastic production. Many sectors continue to rely on primary plastics for a range of quality, economic and regulatory reasons (OECD, 2022). The wide use of additives represents a genuine barrier to the secondary plastics market because of difficulties in extracting impurities and POPs, and the limited number of applications for low-grade recycled plastic materials (OECD, 2022).

The business case for secondary plastics is strongly affected by regulation. There are high landfill and incineration taxes. However, for these to drive increased plastics recycling, they will need to be accompanied by strong environmental standards and enforcement (OECD, 2018). Some countries have strengthened their secondary plastic markets policies to 'push' supply through the use of taxes on non-recycled plastic waste and 'pull' demand using recycled content targets (OECD, 2022). The case for PVC is slightly at variance with plastics in general. Disposal of waste to landfill is being increasingly replaced by energy recovery, but there are technical challenges around the halogen content in PVC. Therefore, such technical challenges may potentially be pushing the PVC sector towards increased recycling (EA, pers. comm).

Restrictions on the use of specific additives may facilitate the more widespread production and use of secondary plastics as there will be lower concern about the release of harmful chemicals from the plastic during the recycling stages. There is also a long-term issue as it is the regulation in place at the time of disposal that will determine the economic feasibility of plastic recycling, rather than at the time of manufacture. This can be significant for products such as PVC which have a long lifetime, especially if scientific understanding and legislation has evolved over time (EA, pers. comm).

However, many additives serve key functions either at the production phase or during the service life of a product. Thus, their removal from formulations may not be simple. Greater understanding of how issues caused by the inclusion of additives may be avoided is needed to achieve the dual benefits of product performance whilst minimising environment impact.

7. PVC end-of-life treatment in the UK

7.1 Waste composition

PVC is currently the third most used polymer worldwide, following polypropylene and polyethylene terephthalate (PET). This is mainly due to its varied applications and uses as reported in Figure 7-1 below. This variety of products has a considerable impact on the waste management operations and applications as described in the following sections.

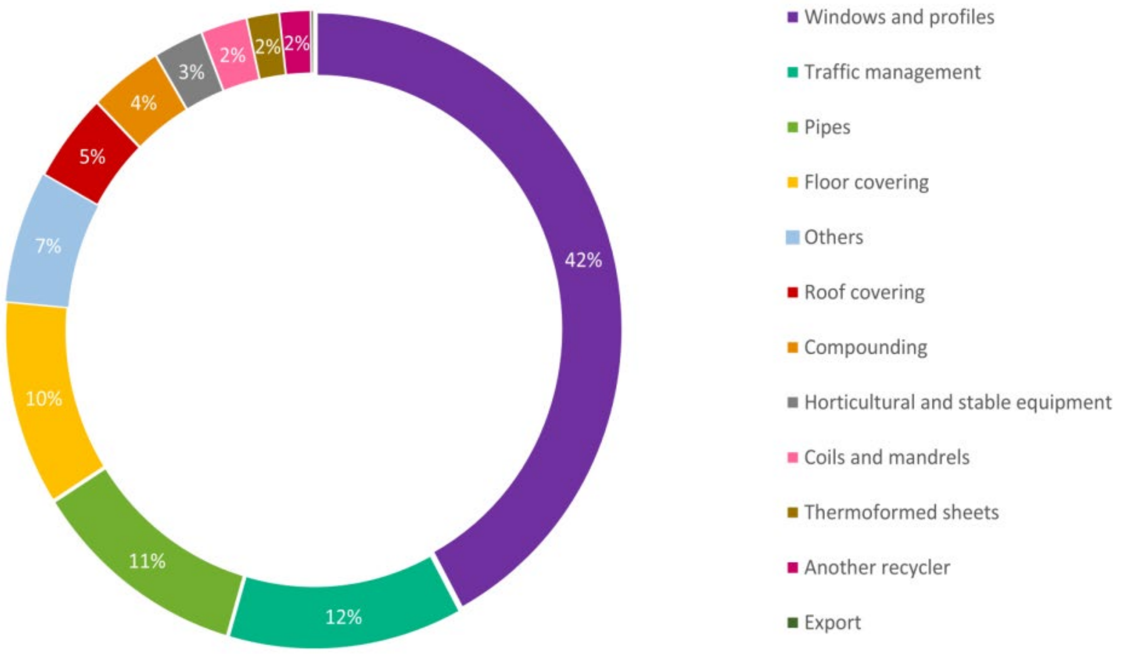


Figure 7-1. PVC Waste Composition / Application split

In addition to its different forms, PVC waste is often characterised into the following categories (The European Council of Vinyl Manufacturers, 2022):

a) **Production residues -** These arise mostly in the form of off-cuts as a product is made in a factory or plant. For many years, such valuable 'waste' has been recycled as a matter of good housekeeping and only a small proportion is disposed of into landfill, or by combustion.

b) **Installation waste -** These result from sold products, such as flooring, cables and pipes being cut to size during installation. In recent years, the PVC industry has become active in organising collection systems and recycling these ‘waste' products back into new products.

c) **Post-consumer waste** - This waste consists of products which have fulfilled their service life, originating from various domestic and industry sectors.

Most PVC products have a long service life. In building and construction, for example, estimated lifespans of 50 to 100 years are realistic. As a result, the quantity of used PVC items entering the waste stream is still relatively small and accounts for less than half of the production of PVC products. However, this situation will change over time as greater numbers of these PVC products approach the end of their useful economic lives and begin to slowly increase the volume of the PVC waste stream.

Lastly PVC materials are often characterised by the additives they contain:

- Legacy (additives) PVC
- Conventional (additives) PVC

7.2 Overview of current recycling performance

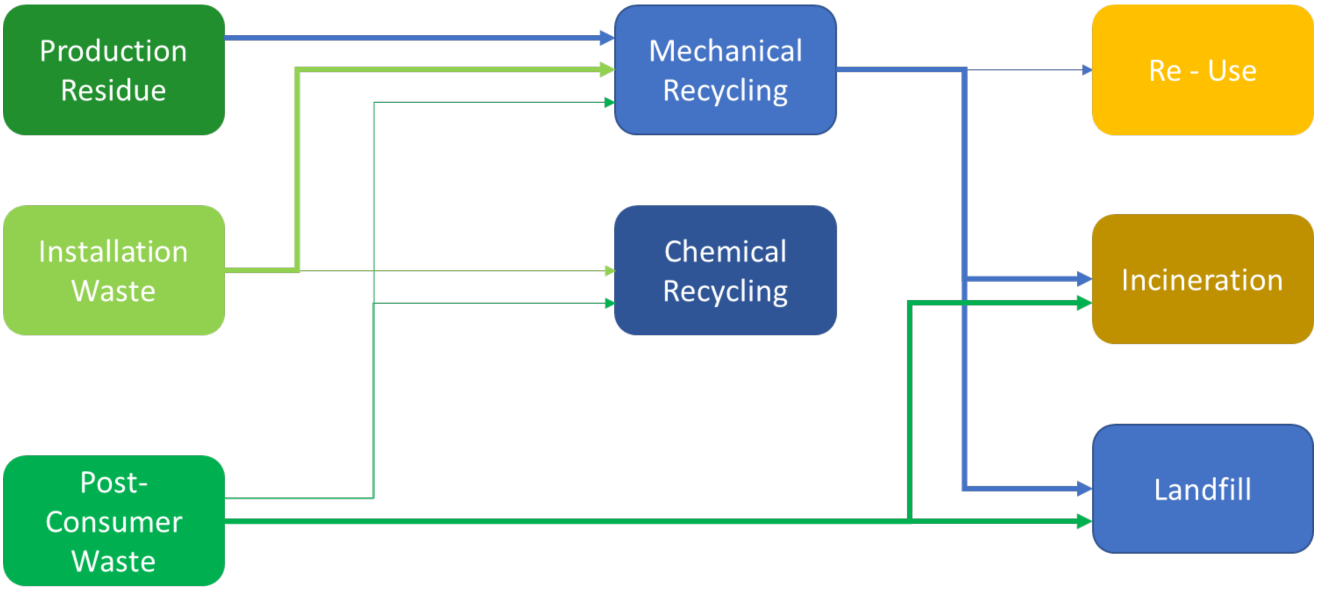
The UK PVC recycling market is one of the most advanced in the world. In 2021 alone, 139,426 tonnes of PVC were recycled in the UK and Ireland, the second highest tonnage of any European country. Given the size and importance of this market, both domestically and internationally, and the stringent environmental laws in the UK, it is imperative that UK regulators work with operators to ensure they have appropriate environmental permits and are compliant with relevant legislation. This must include assessment of the controls set by the UN Basel Convention in relation to international waste shipments.

PVC cannot currently be recycled in household waste collections in the UK, limiting the capture rate of this material. Most of the PVC recycled comes from industrial use – from construction companies and PVC product producers, who organise their own collection and treatment services.

The most recent recycling rate reported was 18%, by Recovinyl in 2019 (Recyling Today, 2020). However, this does not account for changes in waste electrical and electronic equipment (WEEE) cable recycling following a review of chemical content of this waste stream led by UK regulators (EA, pers. comm). Recovinyl are an industry group, and operate a voluntary manufacturer take back scheme for recycling PVC waste from the construction and demolition sectors across Europe. In the UK, Recovinyl is represented by the Axion group, who run and operate the take-back scheme. There are currently 23 recyclers enrolled in the UK scheme, giving window and building companies easy access to PVC recycling.

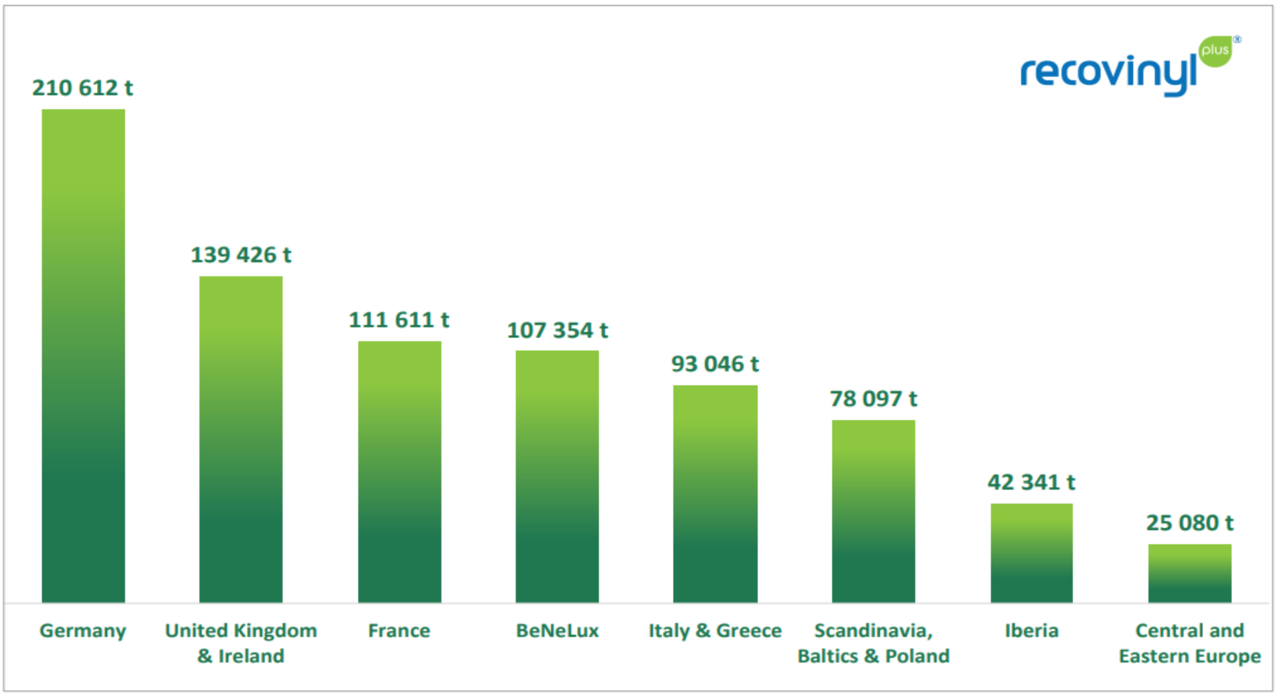
PVC recyclate is commonly used for reproducing window frames, pipes, floor coverings and traffic management infrastructure (e.g., traffic cones). Many recyclers offer a closed-loop service, where waste is collected from waste producers and reprocessed. The recycled product is then returned to the waste producer where it can be used to produce further products. However, more research is needed to assess the potential for leaching of harmful chemicals or impurities from the plastic during the reprocessing phase.

Figure 7-2. End-of-life routes for PVC waste. Thicker lines indicate the most common routes (Ricardo, 2021)



Unfortunately, no information has been generated or reported on the remaining fraction of the waste, and its split between landfilling and incineration.

Figure 7-3. PVC recovery rates (Recovinyl, 2022)



7.3 Current infrastructure

The UK currently has several sites and companies dedicated to PVC recovery and recycling, mostly focused on mechanical technologies. A list of the main processors has been reported below in the following tables.

Table 7-1. Main PVC Mechanical recyclers and Processors in UK (ENF Recycling, 2022).

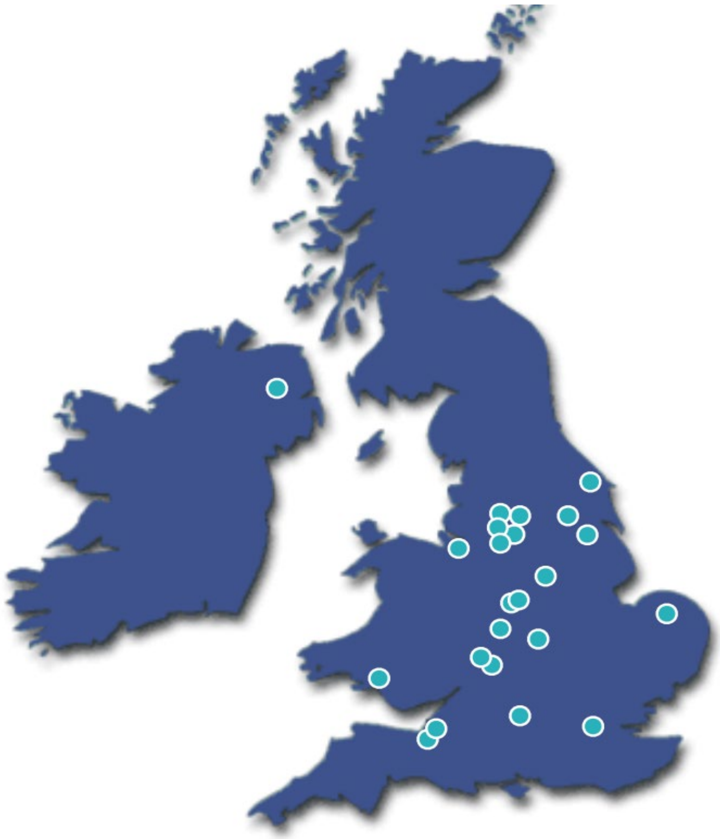
Facility	Location	Activity	Waste accepted	Product
Associated Polymer Resources	Hampshire	Collection, mechanical recycling	Mixed Plastics	Pellets
Avon Reclamation	Somerset	Collection, mechanical recycling	PVCu frames	PVCu granules
BM Tech	Derbyshire	Collection, mechanical recycling	uPVC (from water treatment)	Granules
CL Rye	Essex	Collection, mechanical recycling	PVC	Granules
Eurocell	Derbyshire	Mechanical recycling, Window profile production	PVCu	Granules, PVC profiles
FGD Recycling	Hertfordshire	Mechanical recycling	Mixed Plastics	PVC regrind
GD Environmental Services	Newport	Collection, Mechanical recycling	PP, PE, PVC	PVC regrind
GK recycling	Nottingham	Collection, Mechanical recycling	uPVC window frames	PVC regrind
K2 polymers	Leicestershire	Mechanical recycling	Subsea cables	Pellets
Light Brothers	East Sussex	Mechanical recycling	Food trays, cling film	Granules
Migrama Plastics	West Midlands	Mechanical recycling	uPVC`	PVC regrind
Morris Recycling	Northamptonshire	Mechanical recycling	PVC window frames	Regrind, Pellets, Shreds
Penfold Plastics	North Somerset	Collection from window fabricators, recycling	PVC window frames	PVC regrind, powder
Radical Waste group	Suffolk	Mechanical recycling	Scrap PVC	PVC granules
RUBBER AND PLASTIC COLLECTION	Berkshire	Collection, Mechanical recycling	All types of PVC	Pellets, shreds, regrind, pulver
Sharp Polymers Solutions Limited	Scottish Borders	Collection, Mechanical recycling	Construction Industry PVC	Granules

Facility	Location	Activity	Waste accepted	Product
Simplas PVC Recycling	Nottinghamshire	Mechanical recycling	Rigid and flexible PVC	PVC regrind
Trafford Services	Greater Manchester	Collection, Mechanical recycling	uPVC	Regrind, shred, pellet
Veka Recycling	Northamptonshire	Closed loop recycling service	uPVC	Pellets
WRC Recycling	Renfrewshire	Preparation for Reuse, Mechanical recycling	PVC Pipes	Granules

Table 7-2. Main PVC Chemical recyclers and Processors in UK (ENF Recycling, 2022)

Company	Location	Activity	Waste Accepted	Product
INEOS / Recycling Technologies	Swindon	Pyrolysis	Mixed Plastics	Pyrolysis Oil
Quantafuel	Sunderland	Pyrolysis	Mixed Plastics	Pyrolysis Oil
Recycling Technologies	Swindon	Pyrolysis	Mixed Plastics	Pyrolysis Oil
Recycling Technologies	Binn Eco Park	Pyrolysis	Mixed Plastics	Pyrolysis Oil
Itero	Heathrow	Pyrolysis	Mixed Plastics	Pyrolysis Oil

Figure 7-4. Map showing the locations of the main mechanical and chemical PVC processors and recyclers in the UK



7.4 Current recycling challenges

PVC is easy to recycle mechanically, is well suited to most mechanical recycling facilities and is dependent on the waste stream. PVC has also been shown to be suitable for recycling up to 8 times without a measurable decrease in the chain length of its molecules. However, it presents several challenges.

Collection

The main challenge facing PVC recycling is in collecting suitable waste at an acceptable cost, as most PVC is not currently collected in household collections or as commingled waste, and the stream must be clean before it can be reprocessed. This strongly limits its recovery.

Additives

PVC is very long-lasting, and a large proportion of future PVC waste streams could have been in use for 30 to 40 years. This has the potential to present obstacles to recycling as waste could be heavily contaminated by substances that are now restricted (see Section 6.4), or created during weathering. The content of restricted additives may be sufficient to trigger waste controls, although industry awareness of this issue is variable, with many operators working under the assumption that PVC waste is generally non-hazardous (EA, pers. comm). There is a potential that it will be difficult if hazardous waste controls are applied to tracking, fees and environmental permitting (EA, pers. comm).

This restricts the recyclability of older PVC. Processes are being developed to separate these compounds from recyclate so that these materials will be able to be processed alongside other PVC waste in future (Hahladakis et al., 2018).

PVC products can also contain significantly different additives depending on their intended use. In some vinyl flooring the polymer content can be as low as 25% by weight, with the rest made up of additives. This variation in composition causes difficulties in recycling PVC, even when it is separated from other plastics, as the resulting product's composition is difficult to predict.

Processor specialisation

Due to its numerous applications and uses, and their diverse composition, not all PVC materials can be processed at the same time or by the same processors. PVC waste processors specialise in recycling a particular product (i.e., pipes, windows frames, etc.) rather than the polymer itself. This is in direct contrast with what is done in the rest of the plastic recycling industry. This not only increases the overall complexity of PVC recycling, but also does not provide a clear picture of the effective capacity installed in the UK. In some cases the processor may view PVC as a residue from recycling an object with more value, such as in the case of cable strippers who are primarily interested in recovering copper (EA, pers. comm).

Chlorine content

Another major problem for PVC recycling is its high chlorine content, which may result in significant incineration issues (EA, pers. comm) or processing issues for contaminated polymers. For example, if PVC is present in a high-density polyethylene (HDPE) extrusion process, it might generate hydrogen chloride and compromise the entire production batch. This means that PVC cannot be mechanically recycled alongside other plastics and specialist facilities are required.

Lack of data

The lack of recent secondary sources and the lack of experts with specialized knowledge of PVC waste in individual countries are a significant limitation. Data on waste composition and the presence of PVC are either poor, not available or outdated in many countries, including the UK (Miliute-Plepiene et al., 2021). In addition, given the variability associated with the waste PVC collected, and its quality, there is a lack of data on individual processor capacity and the quantity of material sent to landfill or incineration.

7.5 End-of-life treatments

7.5.1 Landfill

7.5.1.1 Process description

The disposal of PVC in landfill is currently one of the most common disposal routes for PVC. It is commonly disposed of in a mixed waste stream and this method of disposal represents loss of a valuable material resource.

The main issue associated with recycling/disposing pathways for PVC is its poor light and thermal stability. Normally, without thermal stabilisers, PVC decomposes at 120-130˚C, going through dehydrochlorination to form polyenes. PVC dechlorination may also occur under UV irradiation, and in the presence of oxygen and moisture, at a very fast pace in conjunction with a peroxidation process leading to the formation of polyenes (Yousif and Hasan, 2015).

Municipal waste landfills are very heterogeneous in terms of waste composition and the disposed materials are subject to a wide range of physical, biological and chemical processes. PVC waste in landfill sites predominantly originates from household and packaging applications that contain calcium/zinc and tin stabilisers, but which have never contained lead- or cadmium-based heat stabilisers. The amount of PVC found in a typical waste site is less than 1 per cent of the total waste, and the content of lead- or cadmium-based stabilisers will generally not exceed 2% of the total PVC quantity.

The PVC industry commissioned a three-year research programme conducted by independent institutes in Germany and Sweden on the long-term performance of PVC waste in landfill, covering a wide range of applications and stabiliser systems. The results showed that the contribution of PVC products to the quantity of heavy metals in municipal solid waste is low. Their research indicated that levels of organotin compounds did not exceed the Predicted No-Effect Concentration (PNEC). There is limited information available on the fate of non-metal additives during landfill disposal.

7.5.2 Incineration

7.5.2.1 Process description

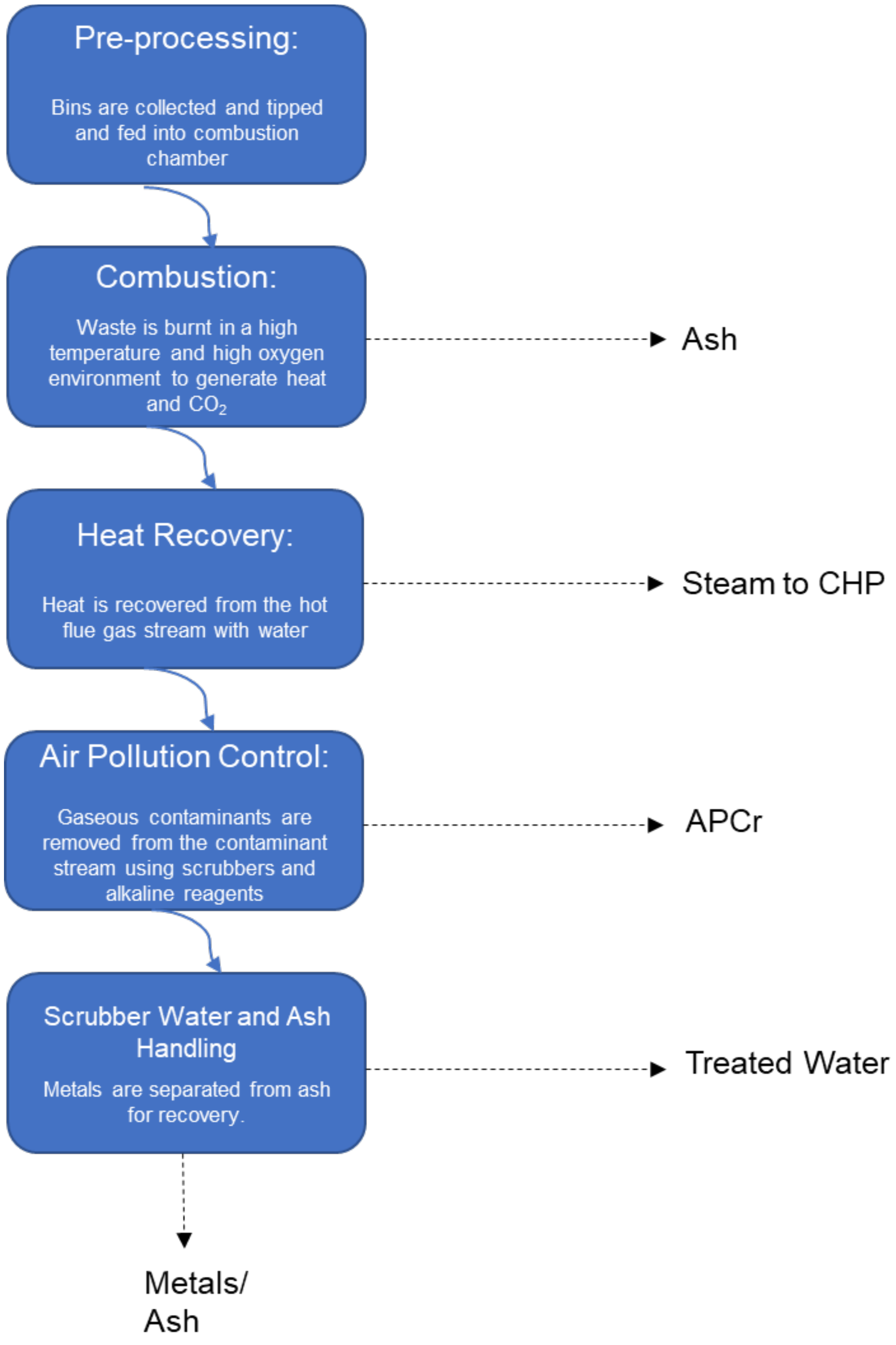
Incineration of polymers takes place when mixed with other solid waste materials. This is particularly important in the case of PVC, as the high chlorine content of this polymer can produce high quantities of hydrogen chloride that potentially but likely to a lesser degree, damage the refractory lining, which must be treated with pollution control systems. During the incineration process, PVC damages the boiler tubes and creates a higher loading for the abatement system. Note that the damages result in an increase in maintenance and downtime costs for the operators. Consequently, operators limit PVC input to their incinerator plants.

The incineration process produces the following output streams:

- Heat
- Electricity
- Incinerator bottom ash
- Metals
- Air pollution control residues
- Emissions to air (off gas)

An indicative flow diagram of the incineration process for mixed solid waste is shown in Figure 7-5.

Figure 7-5. Indicative plastic incineration process flow diagram (Ricardo, 2022)



7.5.2.2 Suitability for PVC

PVC has an energy content of approximately 19 MJ/kg, similar to brown coal and higher than the usual municipal waste used in energy from waste facilities.

The chlorine content of PVC places a high demand on the use of alkaline reagents in air pollution control systems at incinerators, depending on the type of air pollution control technology employed. Each unit of PVC incinerated requires the same amount of these reagents as up to 70 units of municipal solid waste, for the average mix of air pollution abatement systems. This in turn increases the amount of residue generated and requires disposal. These specific costs of PVC incineration (net of energy revenues) amount to some €165/tonne for rigid PVC and €85/tonne for flexible material, for the average estimated mix of air pollution control systems

7.5.3 Mechanical recycling

7.5.3.1 Process description

PVC has been processed by mechanical recycling for many decades and this is a well understood technology. These may involve end-of-chain processors, such as frag plant processing of end-of-life vehicles, approved authorized treatment facilities (AATFs) treating WEEE, and cable strippers (EA, pers. comm).

Mechanical recycling of polymers can be split into two key groups – upcycling or downcycling (Campbell-Johnston et al., 2020) also known as primary or secondary recycling (Schyns and Shaver, 2020).

a) Closed loop recycling (primary recycling) focuses on preserving or improving the properties of post-consumer plastics and developing a process where the final product can be sourced as replacement for virgin material.
b) Downcycling (secondary recycling) focuses on converting post-consumer plastics into useful material but produces a product with lower value than the original item.

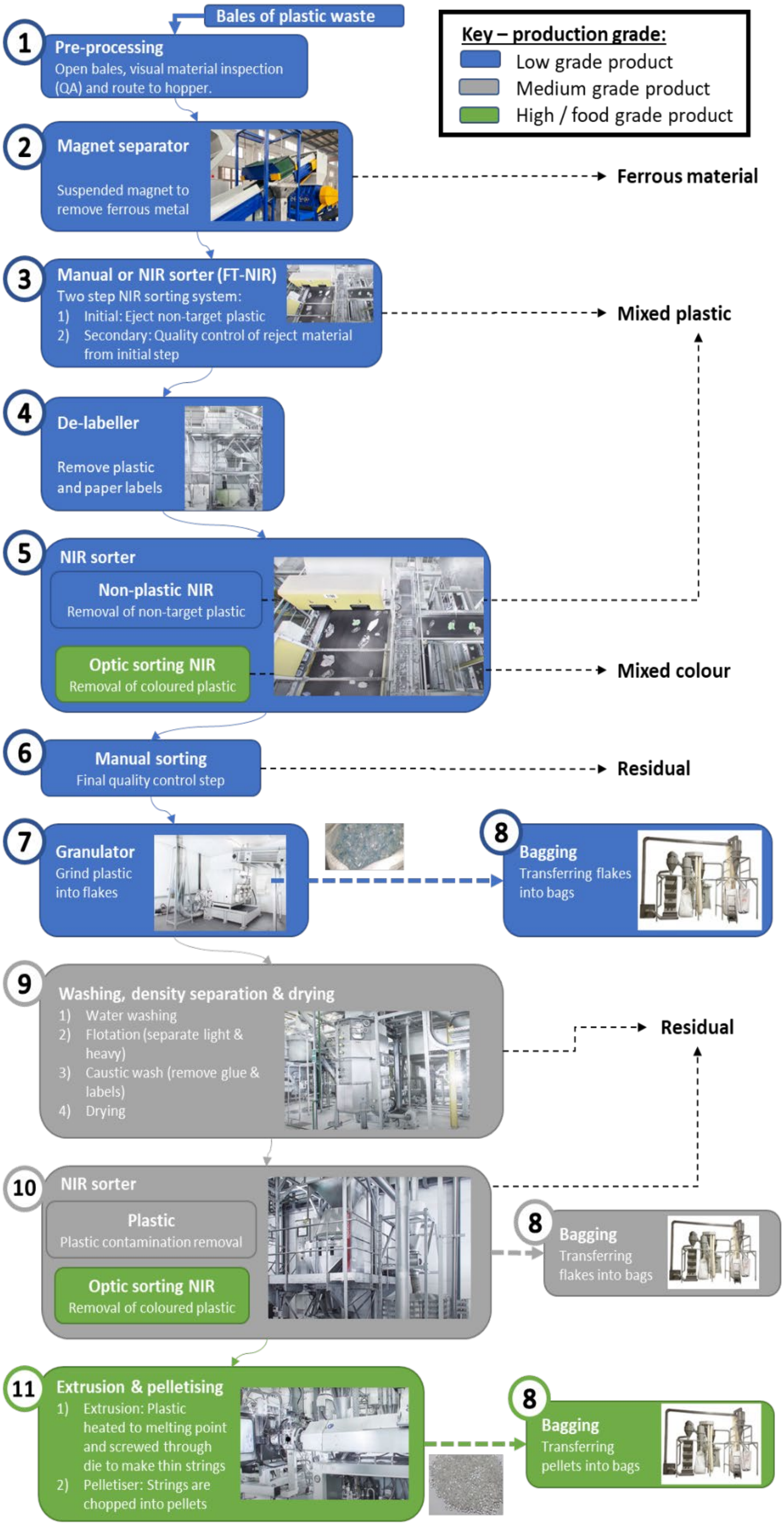
The type and number of process steps included in a mechanical plastic recycling process depends upon the final product that is required, and the feedstock accepted. It is important to note that various operators of mechanical plastics recycling plants will use slightly different process steps, or the process steps may be carried out in a different order (Figure 7-6).

7.5.3.2 Suitability for PVC

The excellent thermoplastic properties of PVC mean that it is well suited to mechanical recycling. Since PVC collection is currently largely from industrial sources, PVC waste streams tend to be cleaner than many other plastic streams.

One complication is the presence of cadmium in some PVC products, leading to a cadmium content within the recycled waste stream. The placing on the market of polymers containing cadmium is restricted by Annex 17 of the UK REACH Regulation (ECHA, 2016a). However, this amendment allows a higher cadmium content in rigid construction products if the cadmium originates from recycling. Cadmium content in recycled PVC needs to be monitored to ensure it does not breach the limits of its intended use.

Figure 7-6. Indicative plastic pelletising process flow diagram (Ricardo, 2022)



7.5.4 Chemical or feedstock recycling

Chemical recycling, also known as feedstock recycling, aims to convert plastic waste into chemicals. It is a process where the chemical structure of the plastic polymer is changed and converted into chemical building blocks including monomers that are then used as a raw material in chemical processes (European Chemical Industry Council - Cefic, 2022).

Chemical recycling is a diverse sector that encompasses several technologies that use solvents, heat, enzymes, and sound waves to convert or purify plastic waste, creating polymers, monomers, oligomers, energy or hydrocarbon products (i.e., fuels, chemicals and fertilisers).

The sector consists of purification, depolymerisation, and conversion technologies that can process a wide range of plastic waste including packaging, textiles, healthcare plastics, and wind turbine blades, addressing overlooked plastics that today do not have end-of-use recovery solutions. Different processes are available for chemical recycling, as reported in Table 7-3.

Table 7-3. Summary of chemical recycling technologies

	Purification	Depolymerisation		Conversion	
		Partial	**Full**	**Partial**	**Full**
Main Polymer Inputs	• Polypropylene • Polyethylene • Polystyrene • ABS Purification processes prefer molecular homogeneity for the feedstock, limiting contamination	• Polyethylene • Polypropylene	• PET •Polyamide (PA) • PS •Polylactic acid (PLA) •Poly(methyl methacrylate) (PMMA) •Polyurethane (PU) •PVC	Mixed (PE, PP, and PS preferred) Including PVC as minor component	Mixed, including PVC as minor component
Technology Feature	Polymer bonds are not broken	• Limited chain scission • Limited side reactions and by-products		• Random chain scission • Side reactions such as cyclisation	• All bonds broken including C-C and C-H • Initial products of process are not hydrocarbons (e.g., syngas from gasification or carbon from flash joule heating)
Typical Technology Output	Colourless polymer flakes or pellets	• Oligomers • PE wax • PP wax	•Monomers (Monoethylene glycol and terphtalic acid) •Solvents •Polyethylene waxstyrenic polymers	• Crude oil • Naphtha • Paraffinic waxes • Alkenes (ethylene & propylene) • BTX • Diesel and other fuels	• Syngas (carbon monoxide and hydrogen mixture) • Methanol • Elemental carbon
Product Feature	Molecular structures of polymers are unchanged from the input material	Specific molecular products (oligomers, narrow distribution waxes)	Specific molecular products (monomers)	• Products consist of mixtures of molecular species, often separated into fractions. • Relatively wide distribution of product molecular weight	Specific molecular products which are often fed directly into another reactor to produce other chemical products such as methanol or hydrocarbons
Technology Types	Solvent extraction, de-inking	Enzymatic degradation, microorganism degradation, solvolysis (e.g., hydrolysis, glycolysis, methanolysis, ammonolysis), pyrolysis (also microwave assisted pyrolysis), hydrothermal, microwave, ultrasonic			Gasification, flash joule heating, plasma-arc gasification

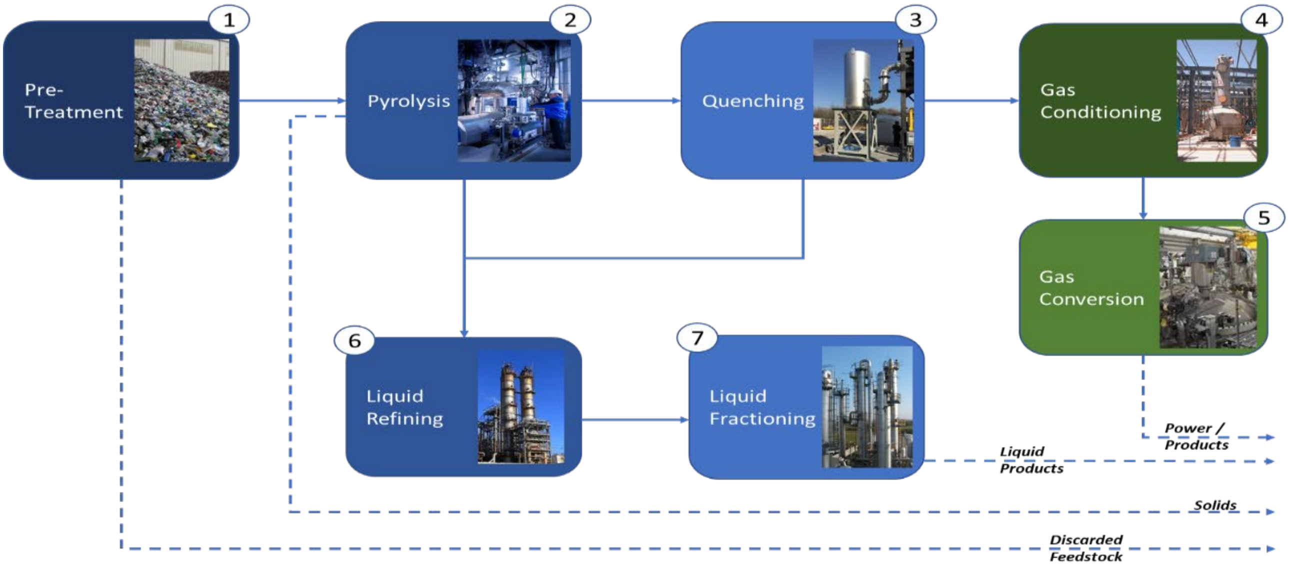
7.5.5 Conversion technologies

Despite the presence of multiple technologies, advanced thermal treatments or full conversion technologies are the most dominant on the market (pyrolysis and gasification).

7.5.5.1 Pyrolysis

Pyrolysis is currently the most mature and readily available technology for the chemical treatment of plastics. Pyrolysis uses the addition of heat in an oxygen free environment to break the polymer structure into its individual monomers. The process takes place at high temperatures of 300-900 ˚C, depending on process configuration. A typical pyrolysis process flow diagram has been presented in Figure 7-7.

Figure 7-7. Pyrolysis process flow diagram (Ricardo, 2022)



The products of the pyrolysis process are

- Heat
- Pyrolysis oil
- Biochar
- Syngas

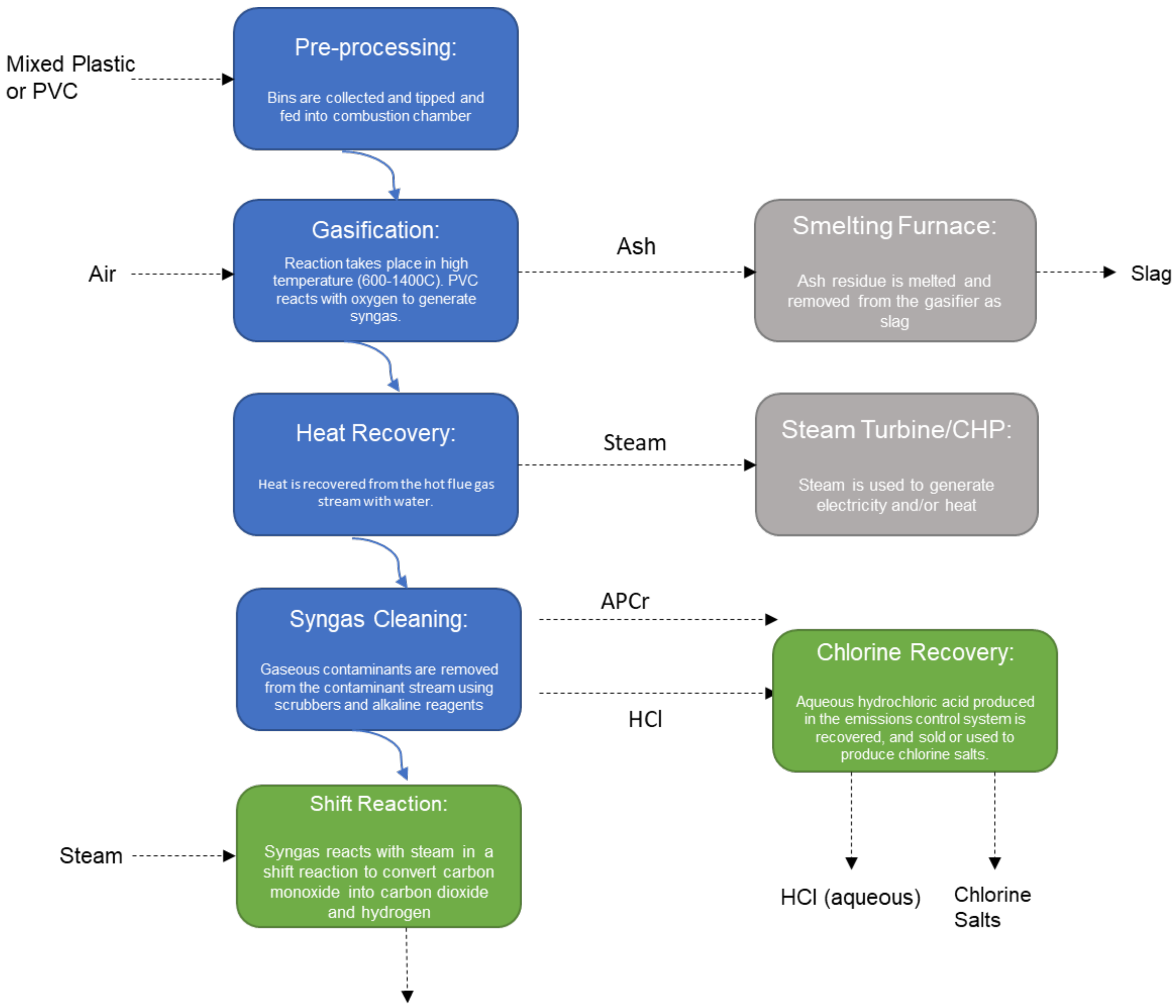
7.5.5.2 Gasification

Like pyrolysis, gasification is a high-temperature, high pressure reaction which causes decomposition of the PVC polymers. Gasification is undertaken under restricted amounts of oxygen, air or steam. The products of this reaction are:

- Carbon Dioxide
- Syngas (methane, hydrogen, and CO2)
- Heat
- Slag

Gasification processes operate at temperatures from 600-1400 ˚C, and pressures from 1-10 bar. An indicative flow diagram is shown in Figure 7-8. It is based on the process designed and operated at Sumitomo Metals in Japan.

Figure 7-8. Gasification block flow diagram (Ricardo, 2022)



7.5.5.3 Suitability for PVC

Due to its structure, PVC degrades at lower temperatures than other polymers and can begin at temperatures as low as 250 ˚C (Yu et al., 2015). PVC usually has thermal stabiliser additives to prevent the degradation of the products during their use. The lower temperature requirements indicate it may be easier to treat PVC via pyrolysis than some other plastic products.

However, similar to incineration, the high chlorine content in PVC does lead to a higher chlorine content in the produced waste gas stream. This increases the load on emissions control systems and increases the requirement for air pollution control reactants. For these reasons there are currently no large-scale pyrolysis or gasification plants treating PVC in Europe.

Pyrolysis plants are however currently accepting PVC in their feedstock mix, with an average percentage of PVC equal to the 5-10 % by weight. Considering the current installed and future plastic pyrolysis capacity forecasted in the EU alone (3 MT) this would translate to 150-300,000 tonnes of PVC treated via chemical recycling.

7.5.6 Depolymerisation technologies

Despite the dominance of conversion technologies for the chemical recycling of PVC, numerous technology providers are developing new processing routes, mainly through depolymerisation mechanisms. Examples of these technologies are reported in the following sections. However, it is worth mentioning that these technologies still present a low Technology Readiness Level (TRL) and therefore have not been tested at commercial scale yet.

7.5.6.1 Dehydrochlorination

Dehydrochlorination of PVC can take place using two different types of reactants.

- Water based solvents
- Ionic-liquid based solvents (Glas et al., 2014)

7.5.6.2 Water based dehydrochlorination.

The REDOP process targets the mixed plastic fraction from municipal waste, which usually contains around 1% chlorine, with ranges 0.5 to 5.0 wt.% (South East Europe PVC Forum, 2006). The process comprises the following steps:

- Post separation of plastic and paper from municipal solid waste
- Separation of the mixed plastics fraction from the paper fraction
- Dechlorination of the mixed plastics fraction
- Co-injection (together with coal) into a blast furnace to produce pig iron.

Of special interest to the recycling of PVC is the dechlorination step, using a novel process patented by chemical company DSM. The process operates as follows.

- Mixed plastics waste is heated batch-wise in a stirred reactor, releasing HCl. Degradation products from the cellulose still present act as emulsifiers, helping to stabilise the slurry.
- The released HCl is neutralised by the addition of a diluted water-soluble base.
- The non-PVC plastics melt into droplets.
- When the reactor is cooled down, the plastic droplets solidify and yield granules that only need filtering, washing and drying.

7.5.6.3 Dehydrochlorination in ionic liquids

The dehydrochlorination of PVC in ionic liquids is currently being studied on a pilot scale at KU Leuven, Belgium. This process uses non-volatile ionic liquids to remove hydrogen chloride from the polymer chains. This is then evacuated by a vacuum or gas stream, leaving the dehydrochlorinated PVC to precipitate out of the solution.

7.5.7 Advances in incineration

Normal solid waste energy-from-waste facilities can only tolerate up to 1% chlorine. These processes can accept a limited tonnage of PVC, and this process is not accepted as recycling by waste regulation. Specialist facilities for the incineration of high chlorine waste are increasingly being developed and built and often involve the recovery of chlorine in the form of hydrochloric acid or its neutralised salts. If this recovery takes place, then partial recycling may be claimed.

7.5.7.1 Chlorine recovery

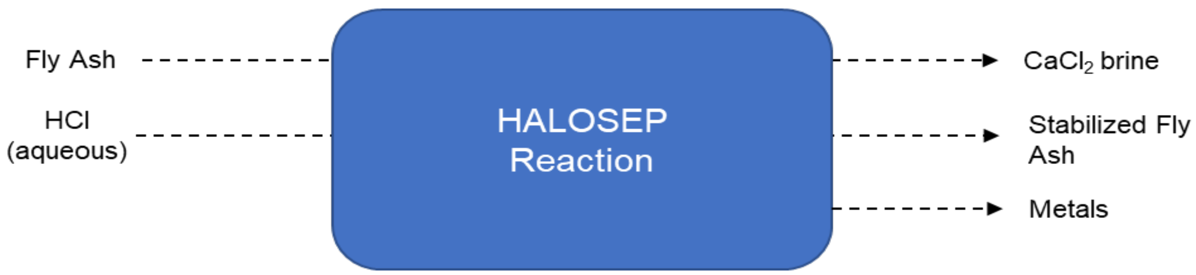
Hydrogen chloride can be recovered from the incineration of wastes containing chlorinated substances. The incineration process takes place as above, exclusively using waste which has a high chlorine content. The flue gas generated therefore can contain a high chlorine percentage.

The hydrogen chloride within the gas stream is absorbed using water scrubbers, generating a 20-30 % (aqueous) hydrochloric acid solution. This product goes through various cleaning processes and has a suitably high purity that it can be used in the chemical industry (VinylPlus, 2016).

Another method of recovering the chlorine produced during the incineration is by the formation of salts of chlorine. One such process is the HALOSEP® process, which recovers salts from waste residues. Alkaline reagents found in fly ash and scrubber liquid are both treated in this process. This leads to two advantages, the reduction of chlorine in flue gas, and a reduction in the amount of flue gas treatment residues that must be disposed of in landfills.

The main product is calcium chloride brine. Successful pilot trials have been carried out and the process will be further developed to licence the technology or build recovery plants. The process is schematically represented in Figure 7-9. Salts can also be recovered as ammonium chloride, which is a useful fertiliser.

Figure 7-9. HALOSEP Block Flow Diagram (HaloSep, 2022)



7.5.8 Advances in recycling

7.5.8.1 Improved separation

As recycling volumes increase, the available waste streams are likely to become more complex and so new processes and technologies are required. There are several developments that could enhance the performance of mechanical recycling through improved separation and detection:

- **Sink/float techniques**, using gravity, water, brine, or other dense media applied to separate waste by density. Due to the higher relative density of PVC compared to other plastics, PVC tends to sink, often resulting in the processors focusing on particles that float (EA, pers. comm).
- **Centrifugal separation**
- **Froth flotation** – Collecting resins of different materials using specific collection oils.
- **Electrostatic separation** – using corona charging or tribo-electric charging to apply charges to certain waste materials.
- **Optical identification** – using electromagnetic radiation sensors to identify several materials, followed then by mechanical or pneumatic separation.

7.5.8.2 VinyLoop

VinyLoop is a patented recycling process developed by the Solvay group to facilitate the recycling of PVC composites. The process separates PVC from other materials through five steps:

- **Pre-treatment:** Waste plastics are cleaned ground and mixed.
- **Dissolution**: PVC is dissolved in a solvent in a closed loop – the solvent is continuously regenerated and can be reused.
- **Filtration and decanting**: Impurities in the PVC waste do not dissolve in the solvent. They are separated by filtration and centrifugal decanting. After separation, secondary materials are washed with more solvent to ensure all PVC is collected.
- **Precipitation**: The PVC in solution is recovered in a precipitation tank where steam is ejected to evaporate the solvent, leaving the PVC solids.
- **Drying**: Excess water is recovered from the slurry and the PVC is sent to a dryer.

The PVC compound produced in this process precipitates as micro granules without the requirement for any grinding (VinylPlus, 2017).

Texyloop is a processing module that acts as an extension to the VinyLoop plant described above. It is designed to treat PVC coated fibres with the aim of recycling both the textile and PVC components. The PVC is dissolved as above, and then polyester fibres are recovered.

Lastly, the European Commission is currently funding, through the Horizon 2020 program, a new eco-friendly recycling technology developed by Circular Flooring for PVC containing “Legacy Additives”. However, the results of the program will not be available before the last quarter of 2024 (European Commission, 2023).

7.6 Potential emissions points

Following the technology review, we have identified potential emission points for additives during treatment of end-of-life PVC:

- Landfill leachate
- Microplastics from granulations and mechanical sorting
- Flue gas from incineration, gasification and pyrolysis
- Bottom ash of incineration and gasification units, in particular the presence of heavy metals (i.e., cadmium, lead, zinc)
- Coke, carbon black or solid residue from pyrolysis units, in particular the presence of heavy metals (i.e., cadmium, zinc)
- Off-specification pyrolysis condensate/oil
- Wastewater from flue gas treatment (scrubbing) from incineration, gasification and pyrolysis plants.
- Wastewater from any activity involving PVC where leaching can occur or particulates are generated.
- Fly ash disposal from gasification and incineration units.

7.7 The effect of PVC additives on recycling processes

It is possible that some PVC additives may have a detrimental effect on the mechanical recycling of PVC. This is due to the potential for any additives present to compromise the integrity of second-generation plastic products. Degradable additives are considered to contaminate the plastics recycling stream and may render the material non-recyclable if this contamination cannot be avoided (The Association of Plastic Recyclers (APR), 2022).

This degradation of additives also occurs during the lifetime of the PVC product. Processes can be put into place during the recycling stage to help reduce any negative effects. Restabilisation using various stabiliser additives during recycling helps to avoid or slow the degradation of the additives, and the addition of fillers and modifiers may improve the plastic's performance once repurposed and protect against degradation. In the case of mixed plastics, the polymers may be compatible in order to obtain secondary plastics which are fit for purpose (Paolo La Mantia, 2011). Impact modifiers may also be added to improve the impact resistance of the recycled plastic (Drip Research Technology Solutions (DRTS), 2018).

8. Conclusions

228 additives present in rigid and/or flexible PVC were identified as relevant to the UK. Information on these additives, including regulatory status, typical concentrations of the additives present within PVC, reported occurrence in monitoring studies and environmental and human health hazards has been collated.

The potential for emissions across the lifecycle of PVC additives has been considered and factors which influence the potential for release identified.

A pragmatic and simple qualitative relative risk ranking has been performed, by considering the likelihood of emissions and hazard posed by the substances. This has enabled us to identify high priority substances (relative to other PVC additives) for further work. In addition, UK specific information on PVC, including changes in the market and waste management practices has been presented for a wider context.

27 substances were identified as a high priority, including flame retardants, heat stabilisers, pigments, plasticisers and slip promoters. However, most of these are already undergoing either formal regulatory scrutiny or are subject to existing risk management measures in the UK or EU. Only 3 are likely to be relevant for further review: tributyl citrate (CAS 77-94-1) (primarily for human health), N-butyl benzene sulfonamide (CAS 3622-84-2) and (Z)-N-octadecyldocos-13-enamide (CAS 10094-45-8). Substances identified as medium priority or data deficient could also be considered as candidates for further assessment.

There is uncertainty around the scale of emissions at each lifecycle phase, with only generic release estimates available. The need for further information on exposure and estimates of release has been identified as an evidence gap.

Most additive emissions are likely to occur during article service life. The concentration of additive in the final article, physicochemical properties of the additive and the associated polymer matrix influence the potential for release, with other factors such as the product's life span and the environmental conditions that the material is exposed to (e.g., indoor or outdoor use) are also significant factors. The key emission forms for additives being emitted to the environment were identified as being particulates, in leachate, by volatilisation or within PVC fragments resulting from abrasion.

The occurrence of PVC additives in the environment and in humans was investigated using environmental monitoring data from the Environment Agency as well as a systematic search of the scientific literature. The plasticiser and flame retardant triphenyl phosphate were the most frequently detected substance in both freshwater and groundwater samples each year in the Environment Agency's GC/LC-MS screening datasets, followed by the plasticisers bis(2-ethylhexyl)adipate and bis-(2-ethylhexyl) phthalate. Bis-(2-ethylhexyl) phthalate was also detected at the highest concentration of the 6 phthalate substances comprising the WIMS dataset, although this dataset had a large proportion of samples with concentrations below the limit of detection. Bis-(2-ethylhexyl) phthalate was reported at the highest median concentrations in surface and ground waters in Europe and the UK in monitoring studies reported in the scientific literature, followed by dibutyl phthalate. Of the PVC additives reported in indoor dust samples in England, three were for plasticisers with a flame-retardant secondary function (triphenyl phosphate, tris(2-ethylhexyl) phosphate, 2-ethylhexyl diphenyl phosphate) and one was a primary flame retardant (1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]). Reported European concentrations were comparable to UK levels for 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene], tris(2-ethylhexyl) phosphate and triphenyl phosphate but were an order of magnitude lower for 2-ethylhexyl diphenyl phosphate than in the UK. European dust data also included a further 14 plasticisers, of which the phthalates occurred at the highest levels. The metabolites of 5 PVC additive substances were detected in urine samples from the UK, all of which were phthalate plasticisers. Their levels of occurrence were comparable to trends seen across Europe, that is, diethyl phthalate > dibutyl phthalate and diisobutyl phthalate and bis-(2-ethylhexyl) phthalate > benzyl butyl phthalate. Diphenyl phosphate and dimethyl phthalate were also detected in European human biomonitoring samples (urine, breast milk, nails) but were not reported in UK studies.

8.1 Recommendations for further work

Substances which have been identified as high priority based on the outcome of the relative risk ranking exercise which are not already currently under formal regulatory scrutiny (tributyl citrate (CAS 77-94-1) (primarily for human health), N-butyl benzene sulfonamide (CAS 3622-84-2) and (Z)-N-octadecyldocos-13-enamide (CAS 10094-45-8)) are highlighted for further work. N-butyl benzene sulfonamide was nominated by the Environment Agency for Substance Evaluation under UK REACH in 2023.

Those substances identified as high or medium priority in this project but not yet routinely monitored to determine their presence within UK waters could be included in emerging contaminant screening monitoring to provide a useful additional line of evidence.

Substances with a lack of hazard and/or tonnage data (2-ethylhexyl diphenyl phosphite (CAS 15647-08-2), hexanedioic acid, polymer with 2,2-dimethyl-1,3-propanediol and 1,2-propanediol, isononyl ester (CAS 208945-13-5), hexanedioic acid, polymer with 1,2-propanediol, octyl ester (CAS 82904-80-1), hexanedioic acid, polymer with 1,2-propanediol, acetate (CAS 55799-38-7), alkylsulfonic acid ester with phenol (CAS 91082-17-6), benzyl C7-9-branched and linear alkyl phthalate (CAS 68515-40-2), diisohexyl phthalate (CAS 146-50-9), di-n-propyl phthalate (CAS 131-16-8)) are data deficient. They might not be commercially important, but the potential risk from these substances is nevertheless currently unknown. Their inclusion in emerging contaminant screening monitoring programmes, where relevant, would help to determine their significance. In addition, lower tonnage PVC additives should be considered as part of any further work on this topic.

Given its widespread detection in surface waters, triphenyl phosphate is also a candidate for further risk assessment in the UK once the Substance Evaluation has been completed under EU REACH (work that was initiated by the UK before EU exit). This substance is used in a variety of materials and is also an impurity in other flame retardants, so this work would extend beyond the use of PVC. Further consideration could also be given to reviewing the plasticiser bis(2-ethylhexyl)adipate for similar reasons.

Bis-(2-ethylhexyl) phthalate is also widely detected but is subject to authorisation in the UK and is also restricted in PVC used indoors. However, there are no controls on imported or recycled PVC articles for use outdoors (such as rainwater collection systems, traffic management infrastructure, hoses, etc.). The continuing widespread detection of this substance could be due to historical uses, but a campaign to measure its presence in imported / recycled articles for use outdoors could provide insight as to whether further controls might be warranted.

Tris(2-ethylhexyl) phosphate, 2-ethylhexyl diphenyl phosphate and (1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]) have been detected in indoor dust, so could also be reviewed from a human health perspective. The latter substance is subject to Substance Evaluation under EU REACH (work that was initiated by the UK before EU exit), so could be reviewed once that work is complete.

Collaboration with PVC industry stakeholders could provide a route for more detailed information on the use of additives across different article types and could facilitate improved exposure scenarios and a more refined quantitative assessment of exposure.

The downstream user import notification (DUIN) information, which comprises of GB-based companies, classed as downstream users, represent an approximate snapshot of substances on the GB market in the period before the EU exit. To reduce uncertainty on PVC additives imported into GB from the EU, the DUIN information for PVC additives will need to be reviewed as part of any further work.

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Appendix 1 Full substance list

Table 10-1. List of PVC additives relevant to the UK

Substance Name	CAS Number	EC Number	Primary Additive Function
Zinc oxide	1314-13-2	215-222-5	Antistatic Agent
Disodium tetraborate, anhydrous	1330-43-4	215-540-4	Antistatic Agent
6,6'-Di-tert-butyl-4,4'-butylidenedi-m-cresol	85-60-9	201-618-5	Antioxidant
4,4',4''-(1-Methylpropanyl-3-ylidene)tris[6-tert-butyl-m-cresol]	1843-03-4	217-420-7	Antioxidant
Octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate	2082-79-3	218-216-0	Antioxidant
Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)	6683-19-8	229-722-6	Antioxidant
2',3-Bis[[3-[3,5-di-tert-butyl-4-hydroxyphenyl]propionyl]]propionohydrazide	32687-78-8	251-156-3	Antioxidant
Ethylenebis(oxyethylene) bis[3-(5-tert-butyl-4-hydroxy-m-tolyl)propionate]	36443-68-2	253-039-2	Antioxidant
Ethanol, 2,2'-iminobis-, N-(C13-15-branched and linear alkyl) derivatives	97925-95-6	308-208-6	Antioxidant
Reaction mass of isomers of: C7-9-alkyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate	125643-61-0	406-040-9	Antioxidant
Azodicarbonamide	123-77-3	204-650-8	Blowing Agent
Kaolin	92704-41-1	296-473-8	Filler
Diantimony trioxide	1309-64-4	215-175-0	Flame Retardant
Paraffin waxes and Hydrocarbon waxes, chloro	63449-39-8	264-150-0	Flame Retardant
Phenol, isopropylated, phosphate (3:1)	68937-41-7	273-066-3	Flame Retardant
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene]	84852-53-9	284-366-9	Flame Retardant
Alkanes, C14-17, chloro	85535-85-9	287-477-0	Flame Retardant
1,1'-(Isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene]	97416-84-7	306-832-3	Flame Retardant
Dibutyltin dilaurate	77-58-7	201-039-8	Heat Stabiliser
Triphenyl phosphite	101-02-0	202-908-4	Heat Stabiliser
Zinc dilaurate	2452-01-9	219-518-5	Heat Stabiliser
Pentalead tetraoxide sulfate	12065-90-6	235-067-7	Heat Stabiliser
Tetralead trioxide sulfate	12202-17-4	235-380-9	Heat Stabiliser
Dioxobis(stearato)trilead	12578-12-0	235-702-8	Heat Stabiliser
2,2-Dioctyl-1,3,2-oxathiastannolan-5-one	15535-79-2	239-581-2	Heat Stabiliser
Methyl (Z,Z)-8,8-dibutyl-3,6,10-trioxo-2,7,9-trioxa-8-stannatrideca-4,11-dien-13-oate	15546-11-9	239-594-3	Heat Stabiliser
2-Ethylhexyl 10-ethyl-4,4-dioctyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	15571-58-1	239-622-4	Heat Stabiliser
2-Ethylhexyl diphenyl phosphite	15647-08-2	239-716-5	Heat Stabiliser
Triisodecyl phosphite	25448-25-3	246-998-3	Heat Stabiliser
Diisodecyl phenyl phosphite	25550-98-5	247-098-3	Heat Stabiliser
Isodecyl diphenyl phosphite	26544-23-0	247-777-4	Heat Stabiliser
2-Ethylhexyl 10-ethyl-4-[[2-[(2-ethylhexyl)oxy]-2-oxoethyl]thio]-4-octyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	27107-89-7	248-227-6	Heat Stabiliser

Substance Name	CAS Number	EC Number	Primary Additive Function
Zinc bis[12-hydroxyoctadecanoate]	35674-68-1	252-669-5	Heat Stabiliser
2-Ethylhexyl 10-ethyl-4-[[2-[(2-ethylhexyl)oxy]-2-oxoethyl]thio]-4-methyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	57583-34-3	260-828-5	Heat Stabiliser
2-Ethylhexyl 10-ethyl-4,4-dimethyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	57583-35-4	260-829-0	Heat Stabiliser
Sulfurous acid, lead salt, dibasic	62229-08-7	263-467-1	Heat Stabiliser
Ethyl 9,9-dioctyl-4,7,11-trioxo-3,8,10-trioxa-9-stannatetradeca-5,12-dien-14-oate	68109-88-6	268-500-3	Heat Stabiliser
Triisotridecyl phosphite	77745-66-5	278-758-9	Heat Stabiliser
Fatty acids, C16-18, lead salts	91031-62-8	292-966-7	Heat Stabiliser
Fatty acids, C16-18, zinc salts	91051-01-3	293-049-4	Heat Stabiliser
Octabenzone	1843-05-6	217-421-2	Light Stabiliser
2-(2H-Benzotriazol-2-yl)-p-cresol	2440-22-4	219-470-5	Light Stabiliser
Bumetrizole	3896-11-5	223-445-4	Light Stabiliser
N-(2-Ethoxyphenyl)-N'-(2-ethylphenyl)oxamide	23949-66-8	245-950-9	Light Stabiliser
2-(2H-Benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)phenol	70321-86-7	274-570-6	Light Stabiliser
A mixture of: bis(2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-1,10-decanedioate; 1,8-bis[(2,2,6,6-tetramethyl-4-((2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-decan-1,10-dioyl)piperidin-1-yl)oxy]octane	129757-67-1	406-750-9	Light Stabiliser
2-(4,6-Diphenyl-1,3,5-triazin-2-yl)-5-((hexyl)oxy)phenol	147315-50-2	411-380-6	Light Stabiliser
Zinc distearate	557-05-1	209-151-9	Lubricant
Ethane-1,2-diyl palmitate	624-03-3	210-826-5	Lubricant
Castor oil, hydrogenated	8001-78-3	232-292-2	Lubricant
Glycerides, C16-18 mono- and di-	85251-77-0	286-490-9	Lubricant
Fatty acids, C16-18, esters with ethylene glycol	91031-31-1	292-932-1	Lubricant
Glycerides, C16-18 mono-	91052-47-0	293-208-8	Lubricant
Fatty acids, C16-18, isotridecyl esters	95912-88-2	306-084-8	Lubricant
Fatty acids, C16-18, C16-18-alkyl esters	97404-33-6	306-797-4	Lubricant
Aluminium-magnesium-zinc-carbonate-hydroxide	169314-88-9	423-570-6	Lubricant
Fatty acids, C8-10, zinc salts	91051-00-2	293-048-9	Nucleating Agent
Glycerides, C16-18 mono-, di- and tri-	91052-54-9	293-215-6	Other Function
Benzenamine, reaction products with aniline hydrochloride and nitrobenzene, hydrochlorides	101357-16-8	309-913-1	Other Function
1,3-Diphenylpropane-1,3-dione	120-46-7	204-398-9	Other Stabilisers
Calcium oxide	1305-78-8	215-138-9	Other Stabilisers
Perylene-3,4:9,10-tetracarboxydiimide	81-33-4	201-344-6	Pigment Agent
6,15-Dihydroanthrazine-5,9,14,18-tetrone	81-77-6	201-375-5	Pigment Agent
29H,31H-Phthalocyaninato(2-)-N29,N30,N31,N32 copper	147-14-8	205-685-1	Pigment Agent
Calcium carbonate	471-34-1	207-439-9	Pigment Agent
29H,31H-Phthalocyanine	574-93-6	209-378-3	Pigment Agent
5,12-Dihydro-2,9-dimethylquino[2,3-b]acridine-7,14-dione	980-26-7	213-561-3	Pigment Agent

Substance Name	CAS Number	EC Number	Primary Additive Function
5,12-Dihydroquino[2,3-b]acridine-7,14-dione	1047-16-1	213-879-2	Pigment Agent
Chromium (III) oxide	1308-38-9	215-160-9	Pigment Agent
Diiron trioxide	1309-37-1	215-168-2	Pigment Agent
Triiron tetraoxide	1317-61-9	215-277-5	Pigment Agent
Titanium dioxde (rutil)	1317-80-2	215-282-2	Pigment Agent
Polychloro copper phthalocyanine	1328-53-6	215-524-7	Pigment Agent
Carbon black	1333-86-4	215-609-9	Pigment Agent
Lead sulfochromate yellow	1344-37-2	215-693-7	Pigment Agent
2-[(4-Methyl-2-nitrophenyl)azo]-3-oxo-N-phenylbutyramide	2512-29-0	219-730-8	Pigment Agent
2,9-bis[4-(phenylazo)phenyl]anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	3049-71-6	221-264-5	Pigment Agent
2,9-Dichloro-5,12-dihydroquino[2,3-b]acridine-7,14-dione	3089-17-6	221-424-4	Pigment Agent
4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-phenyl-3H-pyrazol-3-one]	3520-72-7	222-530-3	Pigment Agent
N,N'-Phenylene-1,4-bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	3905-19-9	223-460-6	Pigment Agent
4,4'-Diamino[1,1'-bianthracene]-9,9',10,10'-tetraone	4051-63-2	223-754-4	Pigment Agent
2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2-methoxyphenyl)-3-oxobutyramide]	4531-49-1	224-867-1	Pigment Agent
2,9-Bis(3,5-dimethylphenyl)anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	4948-15-6	225-590-9	Pigment Agent
2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2,4-dimethylphenyl)-3-oxobutyramide]	5102-83-0	225-822-9	Pigment Agent
Barium bis[2-chloro-5-[(2-hydroxy-1-naphthyl)azo]toluene-4-sulfonate]	5160-02-1	225-935-3	Pigment Agent
N-(4-Chloro-2,5-dimethoxyphenyl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	5280-68-2	226-103-2	Pigment Agent
N,N'-(2-Chloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	5280-78-4	226-106-9	Pigment Agent
3,3'-[(2,5-Dimethyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(5-chloro-o-tolyl)benzamide]	5280-80-8	226-107-4	Pigment Agent
Calcium 3-hydroxy-4-[(4-methyl-2-sulfonatophenyl)azo]-2-naphthoate	5281-04-9	226-109-5	Pigment Agent
2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2-methylphenyl)-3-oxobutyramide]	5468-75-7	226-789-3	Pigment Agent
2,9-Dimethylanthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	5521-31-3	226-866-1	Pigment Agent
3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(3-chloro-o-tolyl)benzamide]	5580-57-4	226-970-7	Pigment Agent
4-[(2,5-Dichlorophenyl)azo]-3-hydroxy-N-phenylnaphthalene-2-carboxamide	6041-94-7	227-930-1	Pigment Agent
2-[(2-Methoxy-4-nitrophenyl)azo]-N-(2-methoxyphenyl)-3-oxobutyramide	6358-31-2	228-768-4	Pigment Agent

Substance Name	CAS Number	EC Number	Primary Additive Function
2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[3-oxo-N-phenylbutyramide]	6358-85-6	228-787-8	Pigment Agent
Calcium 4-[(5-chloro-4-methyl-2-sulfonatophenyl)azo]-3-hydroxy-2-naphthoate	7023-61-2	230-303-5	Pigment Agent
Barium sulfate	7727-43-7	231-784-4	Pigment Agent
Antimony nickel titantium oxide yellow	8007-18-9	232-353-3	Pigment Agent
Cadmium zinc sulfide yellow	8048-07-5	232-466-8	Pigment Agent
Ammonium manganese(3+) diphosphate	10101-66-3	233-257-4	Pigment Agent
Iron manganese trioxide	12062-81-6	235-049-9	Pigment Agent
Pentacalcium hydroxide tris(orthophosphate)	12167-74-7	235-330-6	Pigment Agent
N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	12225-06-8	235-425-2	Pigment Agent
2-[(4-Chloro-2-nitrophenyl)azo]-N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide	12236-62-3	235-462-4	Pigment Agent
Copper chlorophthalocyanine	12239-87-1	235-476-0	Pigment Agent
Calcium bis[4-[[1-[[(2-methylphenyl)amino]carbonyl]-2-oxopropyl]azo]-3-nitrobenzenesulfonate]	12286-66-7	235-558-6	Pigment Agent
Lead chromate molybdate sulfate red	12656-85-8	235-759-9	Pigment Agent
Chromium iron oxide	12737-27-8	235-790-8	Pigment Agent
Ultramarine Violet	12769-96-9	235-811-0	Pigment Agent
Titanium dioxide	13463-67-7	236-675-5	Pigment Agent
Bismuth vanadium tetraoxide	14059-33-7	237-898-0	Pigment Agent
[1,3,8,16,18,24-Hexabromo-2,4,9,10,11,15,17,22,23,25-decachloro-29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32]copper	14302-13-7	238-238-4	Pigment Agent
Strontium 4-[(5-chloro-4-methyl-2-sulfonatophenyl)azo]-3-hydroxy-2-naphthoate (1:1)	15782-05-5	239-879-2	Pigment Agent
4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-(p-tolyl)-3H-pyrazol-3-one]	15793-73-4	239-898-6	Pigment Agent
Tin dioxide	18282-10-5	242-159-0	Pigment Agent
Ammonium iron(3+) hexakis(cyano-C)ferrate(4-)	25869-00-5	247-304-1	Pigment Agent
[N,N,N',N',N'',N''-Hexaethyl-29H,31H-phthalocyaninetrimethylaminato(2-)-N29,N30,N31,N32]copper	28654-73-1	249-125-4	Pigment Agent
3,4,5,6-Tetrachloro-N-[2-(4,5,6,7-tetrachloro-2,3-dihydro-1,3-dioxo-1H-inden-2-yl)-8-quinolyl]phthalimide	30125-47-4	250-063-5	Pigment Agent
2-[[1-[[(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)amino]carbonyl]-2-oxopropyl]azo]benzoic acid	31837-42-0	250-830-4	Pigment Agent
N,N'-(2-Chloro-1,4-phenylene)bis[4-[(4-chloro-2-nitrophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	35869-64-8	252-772-5	Pigment Agent
5,5'-(1H-Isoindole-1,3(2H)-diylidene)dibarbituric acid	36888-99-0	253-256-2	Pigment Agent
N,N'-(2,5-Dichloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	40618-31-3	255-005-2	Pigment Agent
Iron hydroxide oxide yellow	51274-00-1	257-098-5	Pigment Agent
Cadmium sulfoselenide red	58339-34-7	261-218-1	Pigment Agent

Substance Name	CAS Number	EC Number	Primary Additive Function
Methyl 4-[[(2,5-dichlorophenyl)amino]carbonyl]-2-[[2-hydroxy-3-[[(2-methoxyphenyl)amino]carbonyl]-1-naphthyl]azo]benzoate	61847-48-1	263-272-1	Pigment Agent
Calcium 4,5-dichloro-2-[[4,5-dihydro-3-methyl-5-oxo-1-(3-sulfonatophenyl)-1H-pyrazol-4-yl]azo]benzenesulfonate	65212-77-3	265-634-4	Pigment Agent
Cobalt zinc aluminate blue spinel	68186-87-8	269-049-5	Pigment Agent
Zinc iron chromite brown spinel	68186-88-9	269-050-0	Pigment Agent
Chrome antimony titanium buff rutile.	68186-90-3	269-052-1	Pigment Agent
Copper chromite black spinel	68186-91-4	269-053-7	Pigment Agent
Chrome tungsten titanium buff rutile.	68186-92-5	269-054-2	Pigment Agent
Manganese ferrite black spinel	68186-94-7	269-056-3	Pigment Agent
Iron cobalt chromite black spinel	68186-97-0	269-060-5	Pigment Agent
Cobalt chromite blue green spinel	68187-11-1	269-072-0	Pigment Agent
Zirconium praseodymium yellow zircon	68187-15-5	269-075-7	Pigment Agent
Zinc ferrite brown spinel	68187-51-9	269-103-8	Pigment Agent
Manganese antimony titanium buff rutile	68412-38-4	270-185-2	Pigment Agent
Copper, [29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32]-, brominated chlorinated	68512-13-0	270-958-4	Pigment Agent
Tetramethyl 2,2'-[1,4-phenylenebis[imino(1-acetyl-2-oxoethane-1,2-diyl)azo]]bisterephthalate	68516-73-4	271-176-6	Pigment Agent
Hematite, chromium green black	68909-79-5	272-713-7	Pigment Agent
Copper, [29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32]-, chlorinated	68987-63-3	273-501-7	Pigment Agent
Bentonite, acid-leached	70131-50-9	274-324-8	Pigment Agent
Nickel iron chromite black spinel	71631-15-7	275-738-1	Pigment Agent
Calcium bis[4-[[1-[[(2-chlorophenyl)amino]carbonyl]-2-oxopropyl]azo]-3-nitrobenzenesulfonate]	71832-85-4	276-057-2	Pigment Agent
5-[(2,3-Dihydro-6-methyl-2-oxo-1H-benzimidazol-5-yl)azo]barbituric acid	72102-84-2	276-344-2	Pigment Agent
2,2'-[Ethylenebis(oxyphenyl-2,1-eneazo)]bis[N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide]	77804-81-0	278-770-4	Pigment Agent
3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-[2-(4-chlorophenoxy)-5-(trifluoromethyl)phenyl]benzamide]	79953-85-8	279-356-6	Pigment Agent
Copper, [29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32]-, [[3-(1-methylethoxy)propyl]amino]sulfonyl derivatives	81457-65-0	279-767-0	Pigment Agent
Silicic acid, aluminum sodium salt, sulfurized	101357-30-6	309-928-3	Pigment Agent
Silicic acid, zirconium salt, cadmium pigment-encapsulated	102184-95-2	310-077-5	Pigment Agent
Cobalt aluminate blue spinel	1345-16-0	310-193-6	Pigment Agent
3,6-Bis(4-chlorophenyl)-2,5-dihydro-1,4-diketopyrrolo[3,4-c]pyrrole; Pyrrolo[3,4-c]pyrrole-1,4-dione, 3,6-bis(4-chlorophenyl)-2,5-dihydro-	84632-65-5	401-540-3	Pigment Agent
3,6-Bis(4-tert-butylphenyl)-2,5-dihydropyrrolo[3,4-c]pyrrole-1,4-dione	84632-59-7	416-250-2	Pigment Agent
Reaction mass of willemite, white and zinc iron chromite brown spinel	1373399-58-6	936-897-9	Pigment Agent
Tributyl-O-acetyl citrate	77-90-7	201-067-0	Plasticiser

Substance Name	CAS Number	EC Number	Primary Additive Function
Triethyl citrate	77-93-0	201-070-7	Plasticiser
Tributyl citrate	77-94-1	201-071-2	Plasticiser
Dibutyl phthalate	84-74-2	201-557-4	Plasticiser
2,2'-Ethylenedioxydiethyl bis(2-ethylhexanoate)	94-28-0	202-319-2	Plasticiser
Triacetin	102-76-1	203-051-9	Plasticiser
Bis(2-ethylhexyl) adipate	103-23-1	203-090-1	Plasticiser
Dibutyl adipate	105-99-7	203-350-4	Plasticiser
Dimethyl sebacate	106-79-6	203-431-4	Plasticiser
Dibutyl sebacate	109-43-3	203-672-5	Plasticiser
Dihexyl adipate	110-33-8	203-757-7	Plasticiser
Bis-(2-ethylhexyl) phthalate	117-81-7	204-211-0	Plasticiser
Oxydiethylene dibenzoate	120-55-8	204-407-6	Plasticiser
Decanedioic acid, 1,10-bis (2-ethylhexyl) ester	122-62-3	204-558-8	Plasticiser
Di-allyl phthalate	131-17-9	205-016-3	Plasticiser
Di-n-butyl terephthalate	1962-75-0	217-803-9	Plasticiser
Tris(2-ethylhexyl) benzene-1,2,4-tricarboxylate	3319-31-1	222-020-0	Plasticiser
1,3-Propanediol, 2,2-dimethyl-, 1,3-dibenzoate	4196-89-8	224-081-9	Plasticiser
Linseed oil, epoxidized	8016-11-3	232-401-3	Plasticiser
2,2-Bis[[(1-oxopentyl)oxy]methyl]propane-1,3-diyl divalerate	15834-04-5	239-937-7	Plasticiser
Bis(tridecyl) adipate	16958-92-2	241-029-0	Plasticiser
Isobutyric acid, monoester with 2,2,4-trimethylpentane-1,3-diol	25265-77-4	246-771-9	Plasticiser
Diisotridecyl adipate	26401-35-4	247-660-8	Plasticiser
Di-isotridecyl phthalate	27253-26-5	248-368-3	Plasticiser
Di-isodecyl azelate	28472-97-1	249-044-4	Plasticiser
Decanedioic acid, 1,10-diisodecyl ester	28473-19-0	249-047-0	Plasticiser
Diisononylphthalate	28553-12-0; 68515-48-0	249-079-5	Plasticiser
Diisononyladipate	33703-08-1	251-646-7	Plasticiser
Bis(2-propylheptyl) phthalate	53306-54-0	258-469-4	Plasticiser
1,2-Benzenedicarboxylic acid, di-C11-14-branched alkyl esters, C13-rich	68515-47-9	271-089-3	Plasticiser
Di-C8-10-Branched alkyl esters, C9-rich	68515-48-0	271-090-9	Plasticiser
Di-C9-11-Branched alkyl esters, C10-rich; Di-isodecyl phthalate	68515-49-1	271-091-4	Plasticiser
1,2-Benzenedicarboxylic acid, di-C16-18-alkyl esters	90193-76-3	290-580-3	Plasticiser
1,2,4-Benzenetricarboxylic acid, tri-C9-11-alkyl esters	94279-36-4	304-780-6	Plasticiser
1,2-Cyclohexanedicarboxylic acid, diisononyl ester, reaction products of hydrogenation of di-isononylphthalates (n-butenes based); Di-isononyl cyclohexanoate	166412-78-8	431-890-2	Plasticiser
Nonylbenzoate, branched and linear	670241-72-2	447-010-5	Plasticiser
Dioctyl terephthalate	6422-86-2	229-176-9	Plasticiser
N-Butyl benzene sulfonamide	3622-84-2	222-823-6	Plasticiser
Diethylsuccinate	123-25-1	204-612-0	Plasticiser
Dimethylsuccinate	106-65-0	203-419-9	Plasticiser
Di-2-ethylhexyl sebacate	122-62-3	204-558-8	Plasticiser

Substance Name	CAS Number	EC Number	Primary Additive Function
Hexanedioic acid, polymer with 2,2-dimethyl-1,3-propanediol and 1,2-propanediol, isononyl ester	208945-13-5		Plasticiser
Hexanedioic acid, polymer with 1,2-propanediol, octyl ester	82904-80-1		Plasticiser
Hexanedioic acid, polymer with 1,2-propanediol, acetate	55799-38-7		Plasticiser
Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6	Plasticiser
2-Ethylhexyl diphenyl phosphate	1241-94-7	214-987-2	Plasticiser
Triphenyl phosphate	115-86-6	204-112-2	Plasticiser
2,2,4-Trimethyl-1,3 pentanediol di-isobutyrate	6846-50-0	29-934-9	Plasticiser
Alkylsulfonic acid ester with phenol	91082-17-6	293-728-5	Plasticiser
Benzyl C7-9-branched and linear alkyl phthalate	68515-40-2	271-082-5	Plasticiser
Diisoundecyl phthalate	85507-79-5	287-401-6	Plasticiser
Diisooctyl phthalate	27554-26-3	248-523-5	Plasticiser
Di-n-octyl phthalate	117-84-0	204-214-7	Plasticiser
Diisoheptyl phthalate	71888-89-6	276-158-1	Plasticiser
Dicyclohexyl phthalate	84-61-7	201-545-9	Plasticiser
Diisohexyl phthalate	146-50-9		Plasticiser
Di-n-hexyl phthalate	84-75-3	201-559-5	Plasticiser
Di-n-pentyl phthalate	131-18-0	205-017-9	Plasticiser
Benzyl butyl phthalate	85-68-7	201-622-7	Plasticiser
Diisobutyl phthalate	84-69-5	201-553-2	Plasticiser
Di-n-propyl phthalate	131-16-8	205-015-8	Plasticiser
Diethyl phthalate	84-66-2	201-550-6	Plasticiser
Dimethyl phthalate	131-11-3	205-011-6	Plasticiser
Epoxidised soybean oil	2232918	232-391-0	Plasticiser
Tri-ethylene glycol dibenzoate	51747-38-7	204-408-1	Plasticiser
Isodecyl benzoate	131298-44-7	421-090-1	Plasticiser
Dipropylene glycol dibenzoate	27138-31-4	248-258-5	Plasticiser
Bis[2-(2-butoxyethoxy)ethyl]adipate	141-17-3	205-465-5	Plasticiser
Di-(2-butoxyethyl)adipate	141-18-4	205-466-0	Plasticiser
Diisodecyl adipate	27178-16-1	248-299-9	Plasticiser
Diisobutyl adipate	141-04-8	205-450-3	Plasticiser
(Z)-N-Octadecyldocos-13-enamide	10094-45-8	233-226-5	Slip Promoter
Fatty acids, C16-18	67701-03-5	266-928-5	Viscosity Modifier

Appendix 2 P, B, M and T criteria

Table 11-1. Summary of the criteria used to assess persistence, bioaccumulation, (eco)toxicity and mobility.

Endpoint	Criteria used
Persistence	
Not persistent	Readily biodegradable, or
	Other information to indicate non-persistence (e.g. evidence of fast hydrolysis, inherent biodegradation, enhanced ultimate biodegradation, STP simulation testing), or
	Not P/vP in simulation tests in soil, water **and** sediment (see half-life criteria below)
Potentially persistent	Not readily biodegradable but no other data available to conclude P/vP or not P
Persistent	Half-lives exceeded in at least one simulation test: >60 days in marine water; or >40 days in fresh or estuarine water, or >180 days in marine sediment. or >120 days in fresh or estuarine water sediment or >120 days in soil
Very persistent	Half-lives exceeded in at least one simulation test: >60 days in marine water, fresh or estuarine water; or >180 days in marine, fresh or estuarine water sediment, or >180 days in soil
Bioaccumulation	
Not bioaccumulative	Log K_{ow} ≤4.5, or
	Experimental aquatic bioconcentration factor (BCF) <2,000
Potentially bioaccumulative	Calculated or no aquatic BCF, **and** log K_{ow} >4.5
Bioaccumulative	Experimental aquatic BCF ≥2,000
Very bioaccumulative	Experimental aquatic BCF ≥5,000
Toxicity	
Not toxic	Lowest chronic NOEC for freshwater or marine organisms > 0.01 mg/L **and** no evidence of long-term toxicity (STOT RE1 or STOT RE2) **and** not carcinogenic (Carc 1A, 1B), mutagenic (Muta 1A, 1B) or toxic for reproduction (Repr 1A, 1B, 2)
Potentially toxic	No chronic NOEC data or notified classifications (not majority) of STOT RE1, STOT RE2, Carc 1A or 1B, Muta 1A, 1B or 2 or Repr 1A, 1B or 2
Toxic	Lowest chronic NOEC for freshwater or marine organisms ≤ 0.01 mg/L, or
	Evidence of long-term toxicity (STOT RE1 or STOT RE2), or
	Carcinogenic (Carc 1A, 1B), mutagenic (Muta 1A, 1B) or toxic for reproduction (Repr 1A, 1B, 2)
Mobility	
Not mobile	Experimental or calculated log organic carbon normalised soil-water partition coefficient (K_{oc}) ≥3
Potentially mobile	Calculated/estimated log K_{oc} <3
Mobile	Experimental log K_{oc} <3
Very mobile	Experimental log K_{oc} <2

Appendix 3 Literature search protocol

Search terms, scope and criteria for inclusion/exclusion

	Description	Inclusion criteria	Exclusion criteria
Population	Additives used in flexible and rigid PVC. Heat stabilisers Lubricants Plasticisers (phthalates) Optional additives: processing aids, impact modifiers, fillers, nitrile rubbers, pigments and Colourants/colourants and flame retardants.	UK relevant additives	Additives in other plastics excluding PVC. Additives not relevant to the UK
Outcome	A list of PVC additives which are relevant to the UK. Use patterns Tonnage Impurities of concern Typical additive concentrations Sector/function-specific use Estimates of release Reported occurrences (environmental, indoor dust and human biomonitoring data) Leaching potential Applications UK Environment	Papers published between 2000 and 2022. All stages of the lifecycle of PVC products Current and previous substances used in PVC. Uses relevant to UK Published in English	Studies before 2000 unless no other data available. Uses outside of the UK Not published in English Detections in human biological samples

Data sources: PubMed, PubChem, Full text Science Direct, Google Scholar.

Screening criteria: Search results will be screened, first, using the title and applying criteria summarised in the table above. Details of accepted papers will be recorded in a spreadsheet and then screened again by reading the abstract or first paragraph. Papers will then be placed into two categories: included and excluded.

Data capture: We will record the date, search engine used, the search string (combinations of key words) and the number of records returned, the results of each search will be saved as a list of references. If an unmanageable number of papers are identified, the exclusion criteria and the focus of research and search terms will be reviewed.

Validity/QA: A second person will independently screen a sample of documents to check that there is no bias. If necessary, remedial actions will be taken to ensure the criteria are applied appropriately.

Appendix 4 List of medium priority substances

The substances in Table 13-1 were shown to be of medium priority for further work based on the outcome of the risk ranking exercise carried out as part of this project. The table includes substance identity, functional category and the EU regulatory status of the substance.

Table 13-1. List of substances shown to be of medium priority based on the outcome of the relative risk ranking.

CAS	Substance name	Functional category	Regulatory status
1314-13-2	Zinc oxide	Antistatic agent	Substance included in the EU CoRAP. Under assessment for "other hazard based concern", consumer use, exposure of environment, "other exposure/risk based concern" and wide dispersive use.
85-60-9	6,6'-Di-tert-butyl-4,4'-butylidenedi-m-cresol	Antioxidants	Substance included in the EU CoRAP. Under assessment as PBT and ED.
6683-19-8	Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)	Antioxidants	None
97925-95-6	Ethanol, 2,2'-iminobis-, N-(C13-15-branched and linear alkyl) derivatives	Antioxidants	Substance information requested under EU REACH due to its potential to be PBT/vPvB
123-77-3	Azodicarbonamide	Blowing agent	Substance of very high concern (SVHC). Included only in the EU REACH candidate list for authorisation, due to its respiratory sensitising properties.
92704-41-1	Kaolin	Filler	None
77-58-7	Dibutyltin dilaurate	Heat stabilisers	None
101-02-0	Triphenyl phosphite	Heat stabilisers	Substance included in the EU CoRAP due to its suspected reproductive toxicant and ED properties.
15546-11-9	Methyl (Z,Z)-8,8-dibutyl-3,6,10-trioxo-2,7,9-trioxa-8-stannatrideca-4,11-dien-13-oate	Heat stabilisers	None
25550-98-5	Diisodecyl phenyl phosphite	Heat stabilisers	Regulatory status under development under EU REACH. Substance not identified as PBT/vPvB under UK REACH
26544-23-0	Isodecyl diphenyl phosphite	Heat stabilisers	Regulatory status under development under EU REACH.
27107-89-7	2-Ethylhexyl 10-ethyl-4-[[2-[(2-ethylhexyl)oxy]-2-oxoethyl]thio]-4-octyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	Heat stabilisers	Substance included in the EU CoRAP, due to its potential ED properties. Note that the substance has been withdrawn from the CoRAP list because the registrant failed to update the dossier by the deadline of the compliance check process (CCH).

CAS	Substance name	Functional category	Regulatory status
57583-34-3	2-Ethylhexyl 10-ethyl-4-[[2-[(2-ethylhexyl)oxy]-2-oxoethyl]thio]-4-methyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	Heat stabilisers	Substance included in the EU CoRAP due to its carcinogenic, mutagenic and reprotoxic properties (CMR). Note that the evaluation process has been suspended.
57583-35-4	2-Ethylhexyl 10-ethyl-4,4-dimethyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate	Heat stabilisers	The substance has been selected for other EU-wide regulatory measures under EU REACH.
68109-88-6	Ethyl 9,9-dioctyl-4,7,11-trioxo-3,8,10-trioxa-9-stannatetradeca-5,12-dien-14-oate	Heat stabilisers	Under EU REACH, ECHA has performed an assessment and requested for further information. Substance not under assessment in UK REACH.
77745-66-5	Triisotridecyl phosphite	Heat stabilisers	None
1843-05-6	Octabenzone	Light stabilisers	Substance included in the EU CoRAP due to its potential ED properties.
70321-86-7	2-(2H-Benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)phenol	Light stabilisers	Under assessment as PBT.
8001-78-3	Castor oil, hydrogenated	Lubricant	None
91031-31-1	Fatty acids, C16-18, esters with ethylene glycol	Lubricant	Further information has been requested under EU REACH.
81-33-4	Perylene-3,4:9,10-tetracarboxydiimide	Pigment agents	Substance included in the EU CoRAP. Under assessment as PBT.
147-14-8	29H,31H-Phthalocyaninato(2-)-N29,N30,N31,N32 copper	Pigment agents	None
574-93-6	29H,31H-Phthalocyanine	Pigment agents	None
1308-38-9	Chromium (III) oxide	Pigment agents	Substance included in the EU CoRAP due to its suspected reprotoxic properties.
1309-37-1	Diiron trioxide	Pigment agents	None
1328-53-6	Polychloro copper phthalocyanine	Pigment agents	None
1333-86-4	Carbon black	Pigment agents	Substance included in the EU CoRAP due to its carcinogenic and suspected reprotoxic properties.
3049-71-6	2,9-Bis[4-(phenylazo)phenyl]anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	None
3905-19-9	N,N'-Phenylene-1,4-bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	None
4051-63-2	4,4'-Diamino[1,1'-bianthracene]-9,9',10,10'-tetraone	Pigment agents	None
4948-15-6	2,9-Bis(3,5-dimethylphenyl)anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	None

CAS	Substance name	Functional category	Regulatory status
5102-83-0	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2,4-dimethylphenyl)-3-oxobutyramide]	Pigment agents	None
5160-02-1	Barium bis[2-chloro-5-[(2-hydroxy-1-naphthyl)azo]toluene-4-sulfonate]	Pigment agents	Substance included in the EU CoRAP due to its suspected carcinogenic properties.
5280-68-2	N-(4-Chloro-2,5-dimethoxyphenyl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	Pigment agents	None
5280-78-4	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	None
5280-80-8	3,3'-[(2,5-Dimethyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(5-chloro-o-tolyl)benzamide]	Pigment agents	None
5281-04-9	Calcium 3-hydroxy-4-[(4-methyl-2-sulfonatophenyl)azo]-2-naphthoate	Pigment agents	None
5521-31-3	2,9-Dimethylanthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	Substance included in the EU CoRAP. Under assessment as PBT.
5580-57-4	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(3-chloro-o-tolyl)benzamide]	Pigment agents	None
6358-31-2	2-[(2-Methoxy-4-nitrophenyl)azo]-N-(2-methoxyphenyl)-3-oxobutyramide	Pigment agents	Substance included in the EU CoRAP. Under assessment as PBT.
6358-85-6	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[3-oxo-N-phenylbutyramide]	Pigment agents	None
7023-61-2	Calcium 4-[(5-chloro-4-methyl-2-sulfonatophenyl)azo]-3-hydroxy-2-naphthoate	Pigment agents	None
7727-43-7	Barium sulfate	Pigment agents	None
8048-07-5	Cadmium zinc sulfide yellow	Pigment agents	None
12225-06-8	N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	Pigment agents	None
12236-62-3	2-[(4-Chloro-2-nitrophenyl)azo]-N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide	Pigment agents	None

CAS	Substance name	Functional category	Regulatory status
13463-67-7	Titanium dioxide	Pigment agents	Substance included in the EU CoRAP due to its carcinogenic and suspected mutagenic properties .
14059-33-7	Bismuth vanadium tetraoxide	Pigment agents	None
14302-13-7	[1,3,8,16,18,24-Hexabromo-2,4,9,10,11,15,17,22,23,25-decachloro-29H,31H-phthalocyaninato(2-)-N29,N30,N31,N32]copper	Pigment agents	None
28654-73-1	[N,N,N',N',N",N"-Hexaethyl-29H,31H-phthalocyaninetrimethylaminato(2-)-N29,N30,N31,N32]copper	Pigment agents	None
30125-47-4	3,4,5,6-Tetrachloro-N-[2-(4,5,6,7-tetrachloro-2,3-dihydro-1,3-dioxo-1H-inden-2-yl)-8-quinolyl]phthalimide	Pigment agents	None
31837-42-0	2-[[1-[[(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)amino]carbonyl]-2-oxopropyl]azo]benzoic acid	Pigment agents	None
35869-64-8	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(4-chloro-2-nitrophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	None
36888-99-0	5,5'-(1H-Isoindole-1,3(2H)-diylidene)dibarbituric acid	Pigment agents	None
40618-31-3	N,N'-(2,5-Dichloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	None
61847-48-1	Methyl 4-[[(2,5-dichlorophenyl)amino]carbonyl]-2-[[2-hydroxy-3-[[(2-methoxyphenyl)amino]carbonyl]-1-naphthyl]azo]benzoate	Pigment agents	None
79953-85-8	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-[2-(4-chlorophenoxy)-5-(trifluoromethyl)phenyl]benzamide]	Pigment agents	None
84632-59-7	3,6-Bis(4-tert-butylphenyl)-2,5-dihydropyrrolo[3,4-c]pyrrole-1,4-dione	Pigment agents	Under assessment as PBT.
28472-97-1	Di-isodecyl azelate	Plasticisers	Substance included in the EU CoRAP due to its suspected PBT/vPvB properties.

CAS	Substance name	Functional category	Regulatory status
28553-12-0	Diisononyl phthalate	Plasticisers	Some uses of this substance are restricted under Annex 17 of REACH.
27554-26-3	Diisooctyl phthalate	Plasticisers	None
71888-89-6	Diisoheptyl phthalate	Plasticisers	None
84-66-2	Diethyl phthalate	Plasticisers	Substance included in the EU CoRAP. Under assessment as ED.
8013-07-8	Epoxidised soybean oil	Plasticisers	None
27178-16-1	Diisodecyl adipate	Plasticisers	None

Appendix 5 Monitoring data

The following section details additional information relating to the collection of monitoring data. This includes:

1) The search queries used to find monitoring data on PVC additives in surface and ground waters, indoor dust and humans in the UK and Europe.
2) Minimum, mean and maximum concentrations of PVC additives detected in UK freshwater monitoring data obtained via GC-MS by the Environment Agency.
3) Minimum, mean and maximum concentrations of PVC additives detected in UK groundwater monitoring data obtained via GC-MS by the Environment Agency.
4) Minimum, mean and maximum concentrations of PVC additives detected in UK freshwater monitoring data obtained via LC-MS by the Environment Agency.
5) Minimum, mean and maximum concentrations of PVC additives detected in UK groundwater monitoring data obtained via LC-MS by the Environment Agency.
6) A summary of PVC additives detected in surface and ground waters, indoor dust, and humans in Europe reported in scientific literature.

Table 14-1. Summary of search queries used to find monitoring data on PVC additives in surface and ground waters, indoor dust and humans in the UK and Europe

Media	Search engine used	Date of search	Search string used		Total no. of papers found
Environmental water	Science Direct	03/01/2023	(PVC or polyvinyl chloride) AND additive* AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	2010-2023	3,294
	Abstract Sifter (PubMed)	03/01/2023	(PVC or polyvinyl chloride) AND additive* AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	No date limit	13
	Science Direct	03/01/2023	(PVC or polyvinyl chloride) AND additive* AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*) AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser)	2010-2023	3,132
	Abstract Sifter (PubMed)	03/01/2023	(PVC or polyvinyl chloride) AND additive* AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*) AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser)	No date limit	10
	Abstract Sifter (PubMed)	03/01/2023	("PVC additive" OR "polyvinyl chloride additive") AND (phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	2010-2023	46
	Abstract Sifter (PubMed)	03/01/2023	("PVC additive" OR "polyvinyl chloride additive") AND (phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND (water OR groundwater OR "drinking water" OR river OR "surface water") AND (environment OR environmental) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	No date limit	5

Media	Search engine used	Date of search	Search string used		Total no. of papers found
Indoor dust	Science Direct	05/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND ("indoor dust") AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	2010-2023	776
	Abstract Sifter (PubMed)	05/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND ("indoor dust") AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	No date limit	16
Human biomonitoring	Science Direct	09/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND human* AND monitoring AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	2010-2023	42,261
	Abstract Sifter (PubMed)	11/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate) AND (detect* OR concentration OR occur*) AND human* AND monitoring AND (antistatic OR antioxidant OR filler OR "flame retardant" OR nucleating OR plastic* OR lubricant OR pigment OR stabiliser) AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	No date limit	164
	Science Direct	10/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate OR) AND (detect* OR concentration OR occur*) AND human* AND biomonitor AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	2010-2023	272
	Abstract Sifter (PubMed)	11/01/2023	("PVC additive" OR "polyvinyl chloride additive" OR phthalate OR phosphite OR citrate OR adipate OR phosphate OR) AND (detect* OR concentration OR occur*) AND human* AND biomonitor AND (UK OR 'UNITED KINGDOM' OR Europe OR Europe*)	No date limit	182

Table 14-2. Summary of PVC additives detected in UK freshwater per year between 2018 and 2021 (concentrations are µg/L)

Compound	2018			2019			2019			2021		
	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.
2-Ethylhexyldiphenyl phosphate	0.01	2.30	0.40	0.01	0.13	0.03	0.01	0.49	0.11	0.01	0.13	0.03
Benzyl butyl phthalate	0.08	4.60	1.21	0.05	0.34	0.12	0.07	0.15	0.10	0.03	0.03	NA
Bis(2-ethylhexyl) adipate	0.01	1.00	0.23	0.01	0.62	0.07	0.02	1.60	0.15	0.02	0.88	NA
Bis-(2-ethylhexyl) phthalate	2.00	20.00	5.10	1.20	26.00	5.36	1.00	24.00	6.40	2.00	20.00	4.13
Diallyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dibutyl phthalate	1.10	1.40	1.27	0.10	16.00	2.43	1.00	2.20	1.54	1.00	1.70	1.22
Dicyclohexyl phthalate	0.10	0.10	NA	0.10	0.18	0.11	0.10	0.10	NA	NA	NA	NA
Diethyl phthalate	1.00	3.70	1.98	1.00	3.70	1.35	NA	NA	NA	1.00	3.20	1.47
Dimethyl phthalate	0.03	0.60	0.09	0.03	16.00	0.17	0.03	2.20	0.12	0.01	1.10	0.08
Di-n-octyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Di-n-pentyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Di-n-propyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Diisobutyl phthalate	NA	NA	NA	0.50	2.70	1.31	NA	NA	NA	NA	NA	NA
Triacetin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tributyl-O-acetyl citrate	0.04	6.00	0.95	0.10	12.00	3.32	1.20	8.10	4.07	1.30	11.00	5.65
Triethyl citrate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Triphenyl phosphate	0.06	85.00	1.18	0.28	3.50	0.75	0.30	2.60	0.72	0.30	9.70	0.73

Source data: Environment Agency, GC-MS water quality semi-quantitative monitoring screen. NA=not applicable

Table 14-3. Summary of PVC additives detected in UK groundwater per year between 2018 and 2021 (concentrations are µg/L)

Compound	2018			2019			2019			2021		
	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.
2-Ethylhexyldiphenyl phosphate	0.01	1.40	0.30	0.01	0.04	0.01	0.01	0.05	0.02	0.01	0.02	0.02
Benzyl butyl phthalate	0.06	0.06	0.06	0.06	0.14	0.11	0.30	0.68	0.50	NA	NA	NA
Bis(2-ethylhexyl) adipate	0.02	0.17	0.04	0.01	0.37	0.06	0.02	0.08	0.05	0.02	0.76	0.12
Bis-(2-ethylhexyl) phthalate	2.00	25.00	4.84	2.00	28.00	5.84	2.00	13.00	5.55	2.10	15.00	5.12
Diallyl phthalate	NA	NA	NA	0.10	0.10	NA	0.10	0.10	NA	NA	NA	NA
Dibutyl phthalate	1.70	15.00	7.42	1.00	15.00	5.10	1.00	12.00	3.10	NA	NA	NA
Dicyclohexyl phthalate	NA	NA	NA	0.10	0.10	NA	NA	NA	NA	NA	NA	NA
Diethyl phthalate	1.00	33.00	6.36	1.00	3.20	1.42	NA	NA	NA	NA	NA	NA
Dimethyl phthalate	0.03	4.80	0.28	0.03	0.29	0.06	0.05	0.82	0.25	0.06	0.06	NA
Di-n-octyl phthalate	NA	NA	NA	0.10	0.10	NA	NA	NA	NA	NA	NA	NA
Di-n-pentyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Di-n-propyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Diisobutyl phthalate	1.00	2.70	1.55	0.53	2.60	1.18	1.10	1.40	NA	NA	NA	NA
Triacetin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tributyl-O-acetyl citrate	0.02	154.00	12.40	1.40	24.00	11.07	1.10	3.30	1.83	NA	NA	NA
Triethyl citrate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Triphenyl phosphate	0.30	7.20	0.99	0.30	4.80	0.70	0.32	4.00	0.99	0.30	1.30	0.63

Source data: Environment Agency, GC-MS water quality semi-quantitative monitoring screen. NA=not applicable

Table 14-4. Summary of PVC additives detected in UK freshwater per year between 2018 and 2021 (concentrations are µg/L)

Compound	2018			2019			2019			2021		
	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.
2-Ethylhexyldiphenyl phosphate	0.01	0.09	0.03	0.01	0.33	0.09	0.01	0.22	0.08	0.01	0.11	0.04
Di-n-hexyl phthalate	0.01	0.43	NA	0.17	0.17	NA	NA	NA	NA	NA	NA	NA
Triphenyl phosphate	0.08	1.00	0.32	0.01	0.50	0.04	0.02	0.24	0.08	0.04	0.43	0.15

Source data: Environment Agency, LC-MS water quality semi-quantitative monitoring screen. NA=not applicable

Table 14-5. Summary of PVC additives detected in UK groundwater per year between 2018 and 2021 (concentrations are µg/L)

Compound	2018			2019			2019			2021		
	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.	Minimum conc.	Maximum conc.	Mean conc.
2-Ethylhexyldiphenyl phosphate	0.01	0.04	0.02	0.01	0.05	0.02	0.01	0.02	0.01	0.01	0.02	0.01
Di-n-hexyl phthalate	NA	NA	NA	0.05	0.07	NA	NA	NA	NA	NA	NA	NA
Triphenyl phosphate	0.07	0.12	NA	0.01	0.16	0.05	0.02	1.00	0.12			

Source data: Environment Agency, LC-MS water quality semi-quantitative monitoring screen. NA=not applicable

Table 14-6. Summary of PVC additives detected in surface and ground waters, indoor dust, and humans in Europe reported in the scientific literature

Substance	Media	Lowest and highest concentrations[1]	Locations	No. of studies	References
1,1'-(Ethane-1,2-diyl)bis[pentabromobenzene]	Indoor dust	<0.01-540	Belgium, Ireland, Norway	3	(Ali et al., 2011, Kademoglou et al., 2017, Wemken et al., 2019)
1,2-Cyclohexanedicarboxylic acid, 1,2-diisononyl ester	Indoor dust	<5-1,051	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
2-Ethylhexyl diphenyl phosphate	Indoor dust	0.04-4	Norway, the Netherlands	3	(Brandsma et al., 2014, Cequier et al., 2014, Kademoglou et al., 2017)
Benzyl butyl phthalate	Indoor dust	0.2-201	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
	Surface water	0.001-1.3	France, Spain, Sweden	4	(Céspedes et al., 2005, Teil et al., 2007, Bastos and Haglund, 2012, Schmidt et al., 2020)
	Urine[2]	3.1-5.4 (range of geomeans)	Ireland	1	(Cullen et al., 2017)
Bis(2-ethylhexyl) adipate	Indoor dust	0.2-276	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Bis(2-propylheptyl) phthalate	Indoor dust	<1-90	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Bis-(2-ethylhexyl) phthalate	Indoor dust	9-1,957	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
	Surface water	<0.3-20.8	France, Poland, Spain, the Netherlands	7	(Céspedes et al., 2005, Teil et al., 2007, Schmidt et al., 2020, Dargnat et al., 2009, Net et al., 2014, Peijnenburg and Struijs, 2006, Bolívar-Subirats et al., 2021)
	Ground water	<0.007-2.7	Austria, France, Poland	3	(Lapworth et al., 2015, Brueller et al., 2018, Kotowska et al., 2020)

Substance	Media	Lowest and highest concentrations[1]	Locations	No. of studies	References
	Urine[2]	1.1-175	Austria, Belgium, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Norway, Portugal, Slovakia, Spain, Sweden	32	(Högberg et al., 2008, Ye et al., 2009, Becker et al., 2009, Frederiksen et al., 2010, Frederiksen et al., 2011, Göen et al., 2011, Koch et al., 2011, Kasper-Sonnenberg et al., 2012, Frederiksen et al., 2013, Tranfo et al., 2013, Zeman et al., 2013, Dewalque et al., 2014a, Dewalque et al., 2014b, Dewalque et al., 2014c, Geens et al., 2014, Langer et al., 2014, Völkel et al., 2014, Černá et al., 2015, Hartmann et al., 2015, Myridakis et al., 2015, Valvi et al., 2015, Cutanda et al., 2015, Axelsson et al., 2015, Pilka et al., 2015, Sabaredzovic et al., 2015, Correia-Sá et al., 2018, Petrovičová et al., 2016, Cullen et al., 2017, Kasper-Sonnenberg et al., 2014, Koch et al., 2017, Kolena et al., 2017, Tranfo et al., 2018)
	Breast milk[2]	0.5-26	Denmark, Finland, Sweden, Switzerland	3	(Main et al., 2006, Högberg et al., 2008, Schlumpf et al., 2010)
	Serum[2]	0.5-8.4	Denmark, Sweden	2	(Högberg et al., 2008)
	Nail[2]	138	Belgium	1	(Alves et al., 2016)
Dibutyl adipate	Indoor dust	<0.2-1	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Dibutyl phthalate	Indoor dust	0.7-230	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
	Surface water	<0.003-6.8[3]	France, Spain, Sweden, the Netherlands	9	(Céspedes et al., 2005, Teil et al., 2007, Schmidt et al., 2020, Dargnat et al., 2009, Net et al., 2014, Peijnenburg and Struijs, 2006, Bolívar-Subirats et al., 2021)
	Ground water	<0.003-0.48	Poland	1	(Kotowska et al., 2020)
	Urine[2]	8-111	Austria, Belgium Denmark, France, Germany, Greece, Ireland, Italy, Norway, Portugal, Slovakia, Spain, Sweden	30	(Högberg et al., 2008, Ye et al., 2009, Becker et al., 2009, Frederiksen et al., 2010, Frederiksen et al., 2011, Göen et al., 2011, Koch et al., 2011, Kasper-Sonnenberg et al., 2012, Frederiksen et al., 2013, Tranfo et al., 2013, Zeman et al., 2013, Dewalque et al., 2014a, Dewalque et al., 2014b, Dewalque et al., 2014c, Geens et al., 2014, Langer et al., 2014, Hartmann et al., 2015, Myridakis et al., 2015, Valvi et al., 2015, Axelsson et al., 2015, Pilka et al., 2015, Sabaredzovic et al., 2015, Correia-Sá et al., 2018, Petrovičová et al., 2016, Giovanoulis et al., 2016, Cullen et al., 2017, Kasper-Sonnenberg et al., 2014, Koch et al., 2017, Kolena et al., 2017, Tranfo et al., 2018)

Substance	Media	Lowest and highest concentrations[1]	Locations	No. of studies	References
	Breast milk[2]	0.5-12	Denmark, Finland, Sweden, Switzerland	3	(Main et al., 2006, Högberg et al., 2008, Schlumpf et al., 2010)
	Serum[2]	0.5	Sweden	1	(Högberg et al., 2008)
	Nail[2]	74-89	Belgium, Norway	2	(Alves et al., 2016, Giovanoulis et al., 2016)
Dibutyl sebacate	Indoor dust	<0.2-0.8	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Diethyl phthalate	Indoor dust	0.2-6.6	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
	Surface water	<0.01-7.0	France, Spain, Sweden	7	(Céspedes et al., 2005, Teil et al., 2007, Dargnat et al., 2009, Bastos and Haglund, 2012, Net et al., 2014, Schmidt et al., 2020, Bolívar-Subirats et al., 2021)
	Ground water	0.13-0.47	Poland	1	(Kotowska et al., 2020)
	Urine[2]	12.1-310	Austria, Belgium, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Norway, Portugal, Slovakia, Spain, Sweden	27	(Högberg et al., 2008, Frederiksen et al., 2010, Frederiksen et al., 2011, Kasper-Sonnenberg et al., 2012, Frederiksen et al., 2013, Tranfo et al., 2013, Zeman et al., 2013, Dewalque et al., 2014a, Dewalque et al., 2014b, Dewalque et al., 2014c, Langer et al., 2014, Völkel et al., 2014, Kasper-Sonnenberg et al., 2014, Hartmann et al., 2015, Myridakis et al., 2015, Valvi et al., 2015, Axelsson et al., 2015, Cutanda et al., 2015, Pilka et al., 2015, Černá et al., 2015, Sabaredzovic et al., 2015, Correia-Sá et al., 2018, Giovanoulis et al., 2016, Cullen et al., 2017, Koch et al., 2017, Kolena et al., 2017, Tranfo et al., 2018)
	Breast milk[2]	0.9-1	Denmark, Finland	1	(Main et al., 2006)
	Serum[2]	0.5	Sweden	1	(Högberg et al., 2008)
	Nail[2]	64-105	Belgium, Norway	2	(Alves et al., 2016, Giovanoulis et al., 2016)
Diisobutyl phthalate	Indoor dust	<0.2-150	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)

Substance	Media	Lowest and highest concentrations[1]	Locations	No. of studies	References
	Urine[2]	9.8-151	Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Norway, Portugal, Slovakia, Spain, Sweden	26	(Högberg et al., 2008, Becker et al., 2009, Ye et al., 2009, Frederiksen et al., 2010, Frederiksen et al., 2011, Koch et al., 2011, Göen et al., 2011, Kasper-Sonnenberg et al., 2012, Frederiksen et al., 2013, Zeman et al., 2013, Dewalque et al., 2014a, Dewalque et al., 2014b, Dewalque et al., 2014c, Langer et al., 2014, Kasper-Sonnenberg et al., 2014, Hartmann et al., 2015, Myridakis et al., 2015, Valvi et al., 2015, Cutanda et al., 2015, Sabaredzovic et al., 2015, Giovanoulis et al., 2016, Petrovičová et al., 2016, Cullen et al., 2017, Kolena et al., 2017, Koch et al., 2017, Correia-Sá et al., 2018)
	Breast milk[2]	24-26	Switzerland	1	(Schlumpf et al., 2010)
	Serum[2]	0.5	Sweden	1	(Högberg et al., 2008)
Diisononylphthalate	Indoor dust	<5-1872	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Dimethyl phthalate	Indoor dust	<0.2-5.6	Sweden	1	(Christia et al., 2019)
	Surface water	<0.01-0.4	France, Sweden	5	(Bastos and Haglund, 2012, Net et al., 2014, Schmidt et al., 2020, Teil et al., 2007)
	Ground water	0.18-0.47	Poland	1	(Kotowska et al., 2020)
	Urine[2]	1.2-2.8	Germany, Norway, Sweden	3	(Ye et al., 2009)
	Breast milk[2]	0.1	Denmark, Finland	1	(Main et al., 2006)
	Nail[2]	90	Norway	1	(Giovanoulis et al., 2016)
Di-n-octyl phthalate	Surface water	0–0.02	France	2	(Schmidt et al., 2020, Teil et al., 2007)
Dioctyl terephthalate	Indoor dust	5.1-764	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Tributyl-O-acetyl citrate	Indoor dust	0.2-119	Belgium, Ireland, Sweden, the Netherlands	1	(Christia et al., 2019)
Tris(2-ethylhexyl) phosphate	Indoor dust	0.1-0.6	Norway	1	(Kademoglou et al., 2017)
	Surface water	<0.001-0.004	Spain	1	(Cristale et al., 2013a)

Substance	Media	Lowest and highest concentrations[1]	Locations	No. of studies	References
Triphenyl phosphate	Indoor dust	0.001-9.9	Germany, Norway, Romania, the Netherlands	7	(Brommer et al., 2012, Dirtu et al., 2012, Brandsma et al., 2014, Cequier et al., 2014, Fromme et al., 2014, Kademoglou et al., 2017, Sugeng et al., 2017)
Paraffin waxes and hydrocarbon waxes, chloro (LCCP)	Breast milk[2]	4.90 - 184	China, Sweden, Norway	1	(Zhou et al., 2020)

Note: 1 - Units: dust = µg/g; urine and nail = µg/g creatinine; water, breast milk and serum = µg/L.

2 - For human samples, the range of medians is given.

3 - 6.8 is a median but the highest value, no range available for that dataset.

Appendix 6 Relative release potentials

Table 15-1. Relative release potential for additives in rigid PVC

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
72102-84-2	5-[(2,3-Dihydro-6-methyl-2-oxo-1H-benzimidazol-5-yl)azo]barbituric acid	Pigment agents	PVC (rigid)	2	2	302.25	0.00	1	L	Medium hazard and Cart, but low UK tonnage
5521-31-3	2,9-Dimethylanthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (rigid)	2	2	418.4	-0.23	2	M	In CoRAP, medium hazard and Cart. No UK tonnage.
36888-99-0	5,5'-(1H-Isoindole-1,3(2H)-diylidene)dibarbituric acid	Pigment agents	PVC (rigid)	2	2	367.27	-0.26	3	M	Medium hazard and Cart. No UK tonnage.
4051-63-2	4,4'-Diamino[1,1'-bianthracene]-9,9',10,10'-tetraone	Pigment agents	PVC (rigid)	1	2	444.4	-0.29	4	M	Medium hazard and Cart. No UK tonnage
81-33-4	Perylene-3,4:9,10-tetracarboxydiimide	Pigment agents	PVC (rigid)	2	2	390.3	-0.50	5	L	Medium hazard and Cart, but low UK tonnage
5281-04-9	Calcium 3-hydroxy-4-[(4-methyl-2-sulfonatophenyl)azo]-2-naphthoate	Pigment agents	PVC (rigid)	2	2	424.4	-0.51	6	M	Medium emissions likelihood, medium hazard
12236-62-3	2-[(4-Chloro-2-nitrophenyl)azo]-N-(2,3-dihydro-2-oxo-1H-	Pigment agents	PVC (rigid)	2	2	416.8	-0.55	7	M	Medium hazard and Cart. No UK tonnage.

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
	benzimidazol-5-yl)-3-oxobutyramide									
31837-42-0	2-[[1-[[(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)amino]carbonyl]-2-oxopropyl]azo]benzoic acid	Pigment agents	PVC (rigid)	2	2	381.3	-0.59	8	M	Medium hazard and Cart. No UK tonnage.
4948-15-6	2,9-Bis(3,5-dimethylphenyl)anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (rigid)	2	2	598.6	-0.62	9	M	Medium hazard and Cart. No UK tonnage.
77804-81-0	2,2'-[Ethylenebis(oxyphenyl-2,1-eneazo)]bis[N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide	Pigment agents	PVC (rigid)	2	2	732.7	-0.80	10	L	Medium hazard and Cart, but low UK tonnage
61847-48-1	Methyl 4-[[(2,5-dichlorophenyl)amino]carbonyl]-2-[[2-hydroxy-3-[[(2-methoxyphenyl)amino]carbonyl]-1-naphthyl]azo]benzoate	Pigment agents	PVC (rigid)	2	2	643.5	-0.85	11	M	Medium hazard and Cart. No UK tonnage.
5468-75-7	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2-methylphenyl)-3-oxobutyramide]	Pigment agents	PVC (rigid)	2	2	657.5	-0.86	12	L	Medium hazard and Cart, but low UK tonnage

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
3905-19-9	N,N'-Phenylene-1,4-bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (rigid)	2	2	794.5	-0.87	13	M	Medium hazard and Cart. No UK tonnage.
12225-06-8	N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	Pigment agents	PVC (rigid)	2	2	572.6	-0.88	14	M	Medium hazard and Cart. No UK tonnage.
1047-16-1	5,12-Dihydroquino[2,3-b]acridine-7,14-dione	Pigment agents	PVC (rigid)	2	2	312.3	-0.88	15	L	Medium hazard and Cart, but low UK tonnage
980-26-7	5,12-Dihydro-2,9-dimethylquino[2,3-b]acridine-7,14-dione	Pigment agents	PVC (rigid)	2	2	340.4	-0.94	16	L	Medium hazard and Cart, but low UK tonnage
35869-64-8	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(4-chloro-2-nitrophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (rigid)	2	2	850	-0.95	17	M	Medium hazard and Cart. No UK tonnage.
6358-31-2	2-[(2-Methoxy-4-nitrophenyl)azo]-N-(2-methoxyphenyl)-3-oxobutyramide	Pigment agents	PVC (rigid)	2	2	386.4	-0.96	18	M	In CoRAP. Medium emissions likelihood and hazard
81-77-6	6,15-Dihydroanthrazine-5,9,14,18-tetrone	Pigment agents	PVC (rigid)	2	2	442.4	-0.98	19	L	Medium hazard and Cart, but low UK tonnage

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
5280-68-2	N-(4-Chloro-2,5-dimethoxyphenyl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)-carbonyl]phenyl]azo]-naphthalene-2-carboxamide	Pigment agents	PVC (rigid)	2	2	611	-1.00	20	M	Medium emissions likelihood and hazard
5280-78-4	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (rigid)	2	2	828.9	-1.04	21	M	Medium hazard and Cart. No UK tonnage. Low release potential due to technical function.
5280-80-8	3,3'-[(2,5-Dimethyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(5-chloro-o-tolyl)benzamide]	Pigment agents	PVC (rigid)	2	2	916.6	-1.05	22	M	Medium hazard and Cart. No UK tonnage.
15793-73-4	4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-(p-tolyl)-3H-pyrazol-3-one]	Pigment agents	PVC (rigid)	2	2	651.5	-1.05	23	L	Medium hazard and Cart, but low UK tonnage
3520-72-7	4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-phenyl-3H-pyrazol-3-one]	Pigment agents	PVC (rigid)	2	2	623.5	-1.07	24	L	Medium hazard and Cart, but low UK tonnage

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
5580-57-4	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(3-chloro-o-tolyl)benzamide]	Pigment agents	PVC (rigid)	2	2	937	-1.07	25	M	Medium hazard and Cart. No UK tonnage.
30125-47-4	3,4,5,6-Tetrachloro-N-[2-(4,5,6,7-tetrachloro-2,3-dihydro-1,3-dioxo-1H-inden-2-yl)-8-quinolyl]phthalimide	Pigment agents	PVC (rigid)	2	2	693.9	-1.12	26	M	Medium hazard and Cart. No UK tonnage.
40618-31-3	N,N'-(2,5-Dichloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (rigid)	2	2	863.3	-1.16	27	M	Medium hazard and Cart. No UK tonnage.
3049-71-6	2,9-Bis[4-(phenylazo)phenyl]anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (rigid)	2	2	750.8	-1.20	28	M	Medium hazard and Cart. No UK tonnage.
01/02/5160	Barium bis[2-chloro-5-[(2-hydroxy-1-naphthyl)azo]toluene-4-sulfonate]	Pigment agents	PVC (rigid)	2	2	888.9	-1.22	29	M	In CoRAP. Medium emissions likelihood and hazard
2512-29-0	2-[(4-Methyl-2-nitrophenyl)azo]-3-oxo-N-phenylbutyramide	Pigment agents	PVC (rigid)	2	2	340.33	-1.29	30	L	Medium Cart, but low UK tonnage and hazard

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
5102-83-0	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2,4-dimethylphenyl)-3-oxobutyramide]	Pigment agents	PVC (rigid)	2	2	685.6	-1.41	31	M	Medium emissions likelihood and hazard
6358-85-6	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[3-oxo-N-phenylbutyramide]	Pigment agents	PVC (rigid)	2	2	629.5	-1.44	32	M	Medium emissions likelihood and hazard
79953-85-8	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-[2-(4-chlorophenoxy)-5-(trifluoromethyl)phenyl] benzamide]	Pigment agents	PVC (rigid)	2	2	1229.2	-1.44	33	M	Medium hazard and Cart. No UK tonnage.
6041-94-7	4-[(2,5-Dichlorophenyl)azo]-3-hydroxy-N-phenylnaphthalene-2-carboxamide	Pigment agents	PVC (rigid)	2	2	436.3	-1.53	34	L	Medium emissions likelihood but low hazard
2440-22-4	2-(2H-Benzotriazol-2-yl)-p-cresol	Light stabilisers	PVC (rigid)	0.0015	0.5	225.25	-1.75	35	L	In CoRAP, but low emission potential
23949-66-8	N-(2-Ethoxyphenyl)-N'-(2-ethylphenyl)oxamide	Light stabilisers	PVC (rigid)	0.7	0.7	312.4	-2.09	36	L	No UK tonnage but low Cart so assume low emission potential

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
36443-68-2	Ethylenebis(oxyethylene) bis[3-(5-tert-butyl-4-hydroxy-m-tolyl)propionate]	Antioxidants	PVC (rigid)	0.005	3	586.8	-2.38	38	L	Medium potential for release but low hazard
101-02-0	Triphenyl phosphite	Heat stabilisers	PVC (rigid)	3	3	310.3	-2.60	40	M	In CoRAP, conservatively M. Substance rapidly hydrolyses to phenol
3896-11-5	Bumetrizole	Light stabilisers	PVC (rigid)	0.3	1	315.8	-2.62	41	L	Low emission potential, M hazard
147315-50-2	2-(4,6-Diphenyl-1,3,5-triazin-2-yl)-5-((hexyl)oxy)phenol	Light stabilisers	PVC (rigid)	6	6	425.5	-2.69	42	L	Low emission potential, low hazard
85251-77-0	Glycerides, C16-18 mono- and di-	Lubricant	PVC (rigid)	1	1	597	-2.76	43	L	Low hazard and emission potential
67701-03-5	Fatty acids, C16-18	Viscosity modifier	PVC (rigid)	1	1	270.5	-2.83	44	L	Low hazard and emissions potential
70321-86-7	2-(2H-Benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)phenol	Light stabilisers	PVC (rigid)	0.2	5	447.6	-2.84	45	M	No UK tonnage but M Cart so potential for emissions
85-60-9	6,6'-Di-tert-butyl-4,4'-butylidenedi-m-cresol	Antioxidants	PVC (rigid)	0.5	0.5	382.6	-2.97	46	M	No UK REACH data, but under assessment as PBT & ED. Included in CoRAP

CAS Number	Substance Name	Primary Function	Polymer Type	Conc. min (%) [Cleaned]	Conc, max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
1843-05-6	Octabenzone	Light stabilisers	PVC (rigid)	0.2	5	326.4	-3.02	47	M	In CoRAP, M Cart and M hazard
624-03-3	Ethane-1,2-diyl palmitate	Lubricant	PVC (rigid)	N/a	N/a	538.9	-4.37	48	L	Lack of emissions data, however hazard is low
8001-78-3	Castor oil, hydrogenated	Lubricant	PVC (rigid)	N/a	N/a	939.5	-4.98	49	M	Low hazard but high UK tonnage.
129757-67-1	A mixture of: bis(2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-1,10-decanedioate; 1,8-bis[(2,2,6,6-tetramethyl-4-((2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-decan-1,10-dioyl)piperidin-1-yl)oxy]octane	Light stabilisers	PVC (rigid)	0.2	0.5	737.1	-4.99	50	L	Low emission potential, low hazard

Table 15-2. Relative release potential for additives found in flexible PVC

CAS Number	Substance Name	Primary Function	Polymer Type	Concentration min (%) [Cleaned]	Concentration max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
5521-31-3	2,9-Dimethylanthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (soft)	2	2	418.4	0.00	1	M	In CoRAP, medium hazard and Cart. No UK tonnage.
12236-62-3	2-[(4-Chloro-2-nitrophenyl)azo]-N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide	Pigment agents	PVC (soft)	2	2	416.8	-0.32	2	M	Medium hazard and Cart. No UK tonnage.
31837-42-0	2-[[1-[[(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)amino]carbonyl]-2-oxopropyl]azo]benzoic acid	Pigment agents	PVC (soft)	2	2	381.3	-0.36	3	M	Medium hazard and Cart. No UK tonnage.
84852-53-9	1,1'-(Ethane-1,2-diyl)bis[pentabromo-benzene]	Flame retardants	PVC (soft)	15	35	971.2	-0.53	4	H	In CoRAP, high potential for release
53306-54-0	Bis(2-propylheptyl) phthalate	Plasticisers	PVC (soft)	10	35	446.7	-0.67	5	H	High release potential, medium hazard
77-90-7	Tributyl-O-acetyl citrate	Plasticisers	PVC (soft)	10	35	402.5	-0.70	6	L	High release potential, low hazard
6358-31-2	2-[(2-Methoxy-4-nitrophenyl)azo]-N-(2-methoxyphenyl)-3-oxobutyramide	Pigment agents	PVC (soft)	2	2	386.4	-0.73	7	M	In CoRAP. Medium emissions likelihood and hazard
122-62-3	Decanedioic acid, 1,10-bis (2-ethylhexyl) ester	Plasticisers	PVC (soft)	10	35	426.7	-0.98	8	L	Medium release potential but low hazard
15834-04-5	2,2-Bis[[(1-oxopentyl)oxy]methyl]propane-1,3-diyl divalerate	Plasticisers	PVC (soft)	10	35	472.6	-1.00	9	L	High release potential, low hazard
94-28-0	2,2'-Ethylenedioxydiethyl bis(2-ethylhexanoate)	Plasticisers	PVC (soft)	n.a.	n.a.	402.6	-1.18	10	L	High UK tonnage but low hazard
3319-31-1	Tris(2-ethylhexyl) benzene-1,2,4-tricarboxylate	Plasticisers	PVC (soft)	35	35	546.8	-1.63	11	H	CoRAP. High release potential, medium hazard. Human health hazard

CAS Number	Substance Name	Primary Function	Polymer Type	Concentration min (%) [Cleaned]	Concentration max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
117-81-7	Bis-(2-ethylhexyl) phthalate	Plasticisers	PVC (soft)	2	35	390.6	-1.71	12	H	SVHC. High hazard and release potential. Human health hazards
68515-49-1	Di-C9-11-Branched alkyl esters, C10-rich; Di-isodecyl phthalate	Plasticisers	PVC (soft)	10	35	446.7	-1.76	13	L	High release potential, low hazard
103-23-1	Bis(2-ethylhexyl) adipate	Plasticisers	PVC (soft)	10	35	370.6	-2.23	14	H	In CoRAP. High release potential and medium hazard
125643-61-0	Reaction mass of isomers of: C7-9-alkyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate	Antioxidants	PVC (soft)	N/a	N/a	376.6	-2.34	15	L	No Cart available. High UK tonnage but low hazard
16958-92-2	Bis(tridecyl) adipate	Plasticisers	PVC (soft)	10	35	510.8	-2.35	16	L	High release potential, low hazard
28553-12-0	Diisononylphthalate	Plasticisers	PVC (soft)	10	35	418.6	-2.44	17	M	assigned L/M (query not P ?) as is UVCB and is potentially B & T. advise review data for P
68515-48-0	Di-C8-10-Branched alkyl esters, C9-rich	Plasticisers	PVC (soft)	10	35	418.6	-2.44	18	L	Low hazard, no UK tonnage data, high cart
33703-08-1	Diisononyladipate	Plasticisers	PVC (soft)	10	35	398.6	-2.69	19	L	Medium release potential but low hazard
4051-63-2	4,4'-Diamino[1,1'-bianthracene]-9,9',10,10'-tetraone	Pigment agents	PVC (soft)	1	2	444.4	-3.22	20	M	Medium hazard and Cart. No UK tonnage
5281-04-9	Calcium 3-hydroxy-4-[(4-methyl-2-sulfonatophenyl)azo]-2-naphthoate	Pigment agents	PVC (soft)	2	2	424.4	-3.44	21	M	Medium emissions likelihood, medium hazard
4948-15-6	2,9-Bis(3,5-dimethylphenyl)anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (soft)	2	2	598.6	-3.55	22	M	Medium hazard and Cart. No UK tonnage.

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77804-81-0	2,2'-[Ethylenebis(oxyphenyl-2,1-eneazo)]bis[N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxobutyramide	Pigment agents	PVC (soft)	2	2	732.7	-3.73	23	L	Medium hazard and Cart, but low UK tonnage
61847-48-1	Methyl 4-[[(2,5-dichlorophenyl)amino]carbonyl]-2-[[2-hydroxy-3-[[(2-methoxyphenyl)amino]carbonyl]-1-naphthyl]azo]benzoate	Pigment agents	PVC (soft)	2	2	643.5	-3.78	24	M	Medium hazard and Cart. No UK tonnage.
5468-75-7	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2-methylphenyl)-3-oxobutyramide]	Pigment agents	PVC (soft)	2	2	657.5	-3.79	25	L	Medium hazard and Cart, but low UK tonnage
4531-49-1	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2-methoxyphenyl)-3-oxobutyramide]	Pigment agents	PVC (soft)	2	2	689.5	-3.80	26	L	Medium hazard and Cart, but low UK tonnage
3905-19-9	N,N'-Phenylene-1,4-bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (soft)	2	2	794.5	-3.80	27	M	Medium hazard and Cart. No UK tonnage.
12225-06-8	N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	Pigment agents	PVC (soft)	2	2	572.6	-3.81	28	M	Medium hazard and Cart. No UK tonnage.
35869-64-8	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(4-chloro-2-nitrophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (soft)	2	2	850	-3.88	29	M	Medium hazard and Cart. No UK tonnage.
81-77-6	6,15-Dihydroanthrazine-5,9,14,18-tetrone	Pigment agents	PVC (soft)	2	2	442.4	-3.92	30	L	Medium hazard and Cart, but low UK tonnage

CAS Number	Substance Name	Primary Function	Polymer Type	Concentration min (%) [Cleaned]	Concentration max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
5280-68-2	N-(4-Chloro-2,5-dimethoxyphenyl)-3-hydroxy-4-[[2-methoxy-5-[(phenylamino)carbonyl]phenyl]azo]naphthalene-2-carboxamide	Pigment agents	PVC (soft)	2	2	611	-3.93	31	M	Medium emissions likelihood and hazard
12286-66-7	Calcium bis[4-[[1-[[(2-methylphenyl)amino]carbonyl]-2-oxopropyl]azo]-3-nitrobenzenesulfonate]	Pigment agents	PVC (soft)	2	2	878.9	-3.94	32	L	Medium hazard and Cart, but low UK tonnage
5280-78-4	N,N'-(2-Chloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (soft)	2	2	828.9	-3.97	33	M	Medium hazard and Cart. No UK tonnage. Low release potential due to technical function.
5280-80-8	3,3'-[(2,5-Dimethyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(5-chloro-o-tolyl)benzamide]	Pigment agents	PVC (soft)	2	2	916.6	-3.98	34	M	Medium hazard and Cart. No UK tonnage.
15793-73-4	4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-(p-tolyl)-3H-pyrazol-3-one]	Pigment agents	PVC (soft)	2	2	651.5	-3.98	35	L	Medium hazard and Cart, but low UK tonnage
3520-72-7	4,4'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[2,4-dihydro-5-methyl-2-phenyl-3H-pyrazol-3-one]	Pigment agents	PVC (soft)	2	2	623.5	-4.00	36	L	Medium hazard and Cart, but low UK tonnage
5580-57-4	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-(3-chloro-o-tolyl)benzamide]	Pigment agents	PVC (soft)	2	2	937	-4.00	37	M	Medium hazard and Cart. No UK tonnage.
30125-47-4	3,4,5,6-Tetrachloro-N-[2-(4,5,6,7-tetrachloro-2,3-dihydro-1,3-dioxo-1H-	Pigment agents	PVC (soft)	2	2	693.9	-4.06	38	M	Medium hazard and Cart. No UK tonnage.

CAS Number	Substance Name	Primary Function	Polymer Type	Concentration min (%) [Cleaned]	Concentration max (%) [Cleaned]	Molecular Weight	RI (Der.)	Ranked Order of Relative Release	Priority Rank	Justification
	inden-2-yl)-8-quinolyl]phthalimide									
40618-31-3	N,N'-(2,5-dichloro-1,4-phenylene)bis[4-[(2,5-dichlorophenyl)azo]-3-hydroxynaphthalene-2-carboxamide]	Pigment agents	PVC (soft)	2	2	863.3	-4.09	39	M	Medium hazard and Cart. No UK tonnage.
3049-71-6	2,9-bis[4-(phenylazo)phenyl]anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetrone	Pigment agents	PVC (soft)	2	2	750.8	-4.13	40	M	Medium hazard and Cart. No UK tonnage.
5160-02-1	Barium bis[2-chloro-5-[(2-hydroxy-1-naphthyl)azo]toluene-4-sulfonate]	Pigment agents	PVC (soft)	2	2	888.9	-4.15	41	M	In CoRAP. Medium emissions likelihood and hazard
5102-83-0	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2,4-dimethylphenyl)-3-oxobutyramide]	Pigment agents	PVC (soft)	2	2	685.6	-4.34	42	M	Medium emissions likelihood and hazard
6358-85-6	2,2'-[(3,3'-Dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[3-oxo-N-phenylbutyramide]	Pigment agents	PVC (soft)	2	2	629.5	-4.37	43	M	Medium emissions likelihood and hazard
79953-85-8	3,3'-[(2-Chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)-azo]]bis[4-chloro-N-[2-(4-chlorophenoxy)-5-(trifluoromethyl)phenyl]-benzamide]	Pigment agents	PVC (soft)	2	2	1229.2	-4.37	44	M	Medium hazard and Cart. No UK tonnage.
6041-94-7	4-[(2,5-Dichlorophenyl)azo]-3-hydroxy-N-phenylnaphthalene-2-carboxamide	Pigment agents	PVC (soft)	2	2	436.3	-4.46	45	L	Medium emissions likelihood but low hazard
147315-50-2	2-(4,6-Diphenyl-1,3,5-triazin-2-yl)-5-((hexyl)oxy)phenol	Light stabilisers	PVC (soft)	6	6	425.5	-4.69	46	L	Low emission potential, low hazard

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10094-45-8	(Z)-N-Octadecyldocos-13-enamide	Slip promoter	PVC (soft)	5	5	590.1	-4.97	47	H	High potential for release and medium hazard
32687-78-8	2',3-Bis[[3-[3,5-di-tert-butyl-4-hydroxyphenyl]-propionyl]]propiono-hydrazide	Antioxidants	PVC (soft)	0.002	3	552.8	-5.00	49	L	Low UK tonnage, low hazard
36443-68-2	Ethylenebis(oxyethylene) bis[3-(5-tert-butyl-4-hydroxy-m-tolyl)propionate]	Antioxidants	PVC (soft)	0.005	3	586.8	-5.02	50	L	Medium potential for release but low hazard
70321-86-7	2-(2H-Benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)phenol	Light stabilisers	PVC (soft)	0.2	5	447.6	-5.03	51	M	No UK tonnage but M Cart so potential for emissions
129757-67-1	A mixture of: bis(2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-1,10-decanedioate; 1,8-bis[(2,2,6,6-tetramethyl-4-((2,2,6,6-tetramethyl-1-octyloxypiperidin-4-yl)-decan-1,10-dioyl)piperidin-1-yl)oxy]octane	Light stabilisers	PVC (soft)	0.2	0.5	737.1	-8.39	53	L	Low emission potential, low hazard

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