# WIDESPREAD CHEMICAL CONTAMINATION OF RECYCLED PLASTIC PELLETS GLOBALLY


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IPEN
for a toxics-free future

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**IPEN** is a network of over 600 non-governmental organizations working in more than 120 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals. IPEN´s campaign on Toxic Chemicals in Plastics seeks to eliminate harm from chemicals in plastics when plastics are produced, used, recycled, and discarded.

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**Front cover: (top) Recycled plastic pellets.** Photo: PANeM, Mauritius**; (bottom) Feeding shredded plastic into an pelleting machine.** Photo: CEJ, Sri Lanka


# CONTRIBUTORS

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- Toxics Link, **India**
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# ABSTRACT

Increased recycling rates is a proposed solution to the current health and environmental crisis that is caused by the massive overproduction of plastics. However, almost all plastics contain toxic chemicals that are not removed during recycling but are carried over to the new products, and the recycling process can even generate new toxic chemicals such as dioxins. The increased recycling is intended to contribute to a so-called circular economy, but plastics containing toxic chemicals should not be recycled. Instead, they should be considered non-circular materials.

This study aimed at increasing the amount of information available about toxic chemicals transferred from plastic waste into recycled plastic pellets globally. Therefore, pellets made from recycled high-density polyethylene, intended for use in new products, were purchased from 24 recycling facilities in 23 countries. The pellets were analyzed to determine the presence of 18 substances, representing three types of toxic chemicals: 11 brominated flame retardants, 6 benzotriazole UV stabilizers and bisphenol A.

None of the samples were free from all the targeted chemicals, and 21 samples contained all three types of chemicals. More than half of the samples contained 11 or more chemicals, and 17 samples contained five or more endocrine disrupting chemicals.

Brominated flame retardants were present in 22 of the samples, with DecaBDE being the most frequently detected, despite its listing under the Stockholm Convention for global elimination in 2017 without any exemptions for recycling. Bisphenol A is increasingly being regulated in many countries because of its health impacts on children but was still detected in 22 of the samples.

All pellet samples contained the UV stabilizer UV-326. Evidence is still emerging, but there are indications that it can impact gene expression related to inflammation and immune responses. The benzotriazole UV stabilizer UV-327 is classified as a Substance of Very High Concern in the EU and was detected in 19 samples. The large number of toxic chemicals in many of the samples highlights the need to also consider the potential for combination effects.

# KEY MESSAGES

- None of the samples were free from chemical contamination
- More than half of the samples contained 11 or more of the 18 targeted chemicals
- 17 samples contained five or more endocrine disrupting chemicals
- Plastic materials containing toxic chemicals should not be recycled but be considered non-circular
- Manufacturers should phase out use of toxic chemicals in plastics, and make sure to disclose any toxic content to downstream users, consumers, recyclers and waste handlers
- Governments should ban the use of groups of toxic chemicals such as brominated flame retardants, bisphenols and benzotriazole UV stabilizers
- Export of plastics and plastic waste containing toxic chemicals should be prohibited, especially electronic waste

Photo: ESDO, Bangladesh

# BACKGROUND

### THE PROBLEM OF TOXIC CHEMICALS IN PLASTIC

The massive overproduction of plastics leads to the generation of large amounts of plastic waste, which often end up being burned, landfilled, or dumped, and which pollute the environment. Also, plastics often contain various toxic chemicals added to provide specific functions such as flexibility, color, and durability (Hahladakis *et al.*, 2018). That means that in addition to the visible impacts of plastic pollution, the chemical pollution caused by how plastic wastes are currently managed can harm human health and cause widespread environmental pollution (Takada, 2021).

The proposed solution to the current plastics crisis that is increasingly gaining traction with governments, industry, and other stakeholders is the concept of a circular economy. This builds on an intention to move from an unsustainable linear system where materials are used up and discarded, to a more sustainable, cyclic system where materials are being produced, used, reused, and recycled in a way that limits extraction of natural resources, associated energy use, and pollution.


Photo: ESDO,

However, moving from this theoretical model towards a practical implementation for plastics comes with several obstacles. One major challenge is the toxic chemicals added to plastics (SCP/RAC, 2020). Plastics containing toxic chemicals should be considered non-circular and phased out since recycling does not remove any chemicals, but instead can both increase the number of toxic chemicals by mixing different types of plastics (Lowe *et al.*, 2021) and generate new toxic contaminants such as dioxins (Budin *et al.*, 2020).

This report seeks to highlight the concerns around this toxic recycling and provide new data on toxic chemicals that are transferred from the recycling process into new products by measuring them in recycled plastic pellets sold around the world.

### RECYCLED PLASTIC PRODUCTS CAN CONTAIN A VARIETY OF TOXIC CHEMICALS

The publicly available information about the extent of the problem with toxic chemicals in recycled plastic is very limited. Also, the awareness about these chemicals and their health impacts is generally very low. However, studies have shown that thousands of additives are indicated for potential use in plastic products, many with hazardous properties (Wiesinger *et al.*, 2021).

New markets are now opening for recycled plastics in many countries, leading to new opportunities for both small- and large-scale commercial recyclers. There are even small recycling units sold for domestic use.[1] However, there is currently no transparency regarding what chemicals are added to plastics and consumers, downstream users, and recyclers have virtually no possibility to find out. Recycling facilities therefore have very limited abilities to exclude plastics containing toxic chemicals.

1 See e.g., https://www.fastcompany.com/40486883/these-diy-machines-let-anyone-recycle-plastic-into-new-products


Photo: ESDO, Bangladesh
Photo: CGFED, Vietnam

Since the trade of plastic products and components is global, this means that it is even more difficult to trace any chemicals in the plastic, especially in low- and middle-income countries with an already low capacity for monitoring and enforcement. This problem is exacerbated by the huge volumes of plastic waste that is shipped from high-income countries, including electronic waste that has a high content of toxic chemicals such as flame retardants and toxic metals.

To start addressing this issue, the European Union recently launched a publicly available database[2] containing information on chemicals classified as Substances of Very High Concern[3] in products. This aims to help consumers make informed purchasing choices and provide waste operators with information to guide decisions on the suitability for re-use and recycling of products. While this tool is mainly aimed at the internal EU market, there is potential for also using it to prevent export of the listed products and waste to low- and middle-income countries.

## TOXIC CHEMICAL ADDITIVES IN PLASTICS

Chemicals that are commonly added to plastic include endocrine-disrupting chemicals such as bisphenols, phthalates, benzotriazole UV stabilizers, heavy metals, and brominated flame retardants. Health impacts that can be caused by these chemicals include cancers; diabetes; kidney, liver, and thyroid impacts; metabolic disorders; neurological impacts; inflammation; alterations to both male and female reproductive development; infertility; and impacts to future generations (Flaws *et al.*, 2020).

Many of these chemicals also have other toxic properties that can lead to health impacts after exposure as described further below.

**Brominated flame retardants (BFRs)** are chemicals added to products to prevent them from catching fire. This practice began in the 1970s in response to fires started by smoldering cigarettes, and notably focused on adding chemicals to the upholstery of furniture rather than requiring additional safety features of cigarettes.[4] They have typically been used in acrylonitrile butadiene (ABS) plastics, polyurethane (PU) foams, and polystyrene (PS) plastics.

There are many different types of brominated flame retardants, including polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), and tet-

2 https://echa.europa.eu/sv/scip
3 https://echa.europa.eu/candidate-list-table
4 https://www.chicagotribune.com/lifestyles/health/ct-met-flames-tobacco-20120508-story.html

rabromobisphenol A (TBBPA), each with their own set of toxic properties. The PBDEs and HBCD are known to disrupt human endocrine, immune, and reproductive functions. They negatively affect the development of the nervous system and can negatively impact the IQ of children (Lyche *et al.*, 2015; Vuong *et al.*, 2020). All the PBDEs and HBCD are now listed under the Stockholm Convention for global elimination.[5] TBBPA, which is a known endocrine-disrupting chemical, is currently the BFR produced in the largest volumes (Kodavanti *et al.*, 2014). Newer BFRs such as BTBPE[6] and OBIND[7] are increasingly being used as replacements instead of the chemicals listed under the Stockholm Convention.

There is extensive biomonitoring evidence of exposure to BFRs in the general population, as well as in children, from its use in electronics and other materials. This includes exposure from indoor air and dietary exposure, neonatal exposure through the placenta, infant exposure through breast milk, and toddler exposure from indoor dust and toys (Fromme *et al.*, 2016; Sugeng *et al.*, 2017).

**Bisphenol A (BPA)** is the most commonly used chemical in the bisphenol group. It is used in a wide range of products such as epoxy paints and glue, food can linings, and thermal paper receipts. It is also used as a building block in polycarbonate plastics, a clear, hard, and brittle plastic used in e.g., baby bottles, sports bottles, and food containers.

BPA is one of the most well studied endocrine-disrupting chemicals and its estrogen-like properties were identified already in the 1930s. Since then, several hundreds of animal studies together with more than a hundred human epidemiological studies have provided evidence of a multitude of health impacts from exposure to BPA, such as disruptions to reproductive functions, metabolism, immune responses, neurological features, and neurobehaviors (Vandenberg *et al.*, 2013; Vom Saal *et al.*, 2021).

BPA has also been shown to impact fetal brain development, leading to regulatory controls specifically on the use of BPA in baby bottles and other food and drink containers for children in an increasing number of countries. In the European Union, BPA is listed as a substance of very high concern (SVHC) and classified as toxic to reproduction, skin sensitizing and endocrine-disrupting. The SVHC classification is the first step towards further controls of a hazardous chemical that signals the need to start phasing it out. It also requires manufacturers and importers of products with a concentration of the chemical above 0.1% to provide users (upon request) with adequate information on the safe use and disposal of the product.

BPA has been detected in human urine, blood, saliva, placental tissue, adipose tissue, and breast milk in many countries around the world (Vandenberg *et al.*, 2010). Reports show widespread exposure in all age groups, but also that children generally have higher urinary levels of BPA than adults (Lehmler *et al.*, 2018). International biomonitoring studies indicate that over 90% of children in the United States, Europe, Asia, and Australia are exposed to BPA. While it is difficult to separate exposure sources for adults since they handle a variety of products that may contain BPA, exposure in children has been coupled to the use of products such as feeding bottles and toys made of polycarbonate plastics (Healy *et al.*, 2015).

**Benzotriazole UV stabilizers (BUVs)** are widely used substances that are added to plastics to prevent degradation from sunlight exposure. They can migrate from plastics e.g. used as food contact materials and have been found in human breast milk (Kim *et al.*, 2019), human urine (Asimakopoulos *et al.*, 2013), and fat tissue (Wang *et al.*, 2015). There are many different types of BUVs in use today but published information about the health and environmental impacts is scarce. However, several BUVs have been shown to be able to cause health impacts such as endocrine disruption (Liang *et al.*, 2017; Sakuragi *et al.*, 2021).

5 http://chm.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx
6 1,2-Bis(2,4,6-tribromophenoxy) ethane
7 Octabromo-1,3,3,-trimethylphenyl-1-indan

## AIM AND APPROACH

The aim of this study was to

- increase the amount of data available about toxic chemicals transferred from plastic waste into recycled plastic pellets globally;
- to use this data to raise awareness of the problem of non-circular plastics entering the recycling system; and
- to highlight the need for transparency and international right-to-know for chemicals in products made both from virgin and recycled plastic.

Therefore, recycled pellets from 24 countries from different regions of the world were purchased for analysis to assess the presence of brominated flame retardants, bisphenol A and UV stabilizers. These chemicals are all indicative of specific sources of plastics used to produce the recycled plastic pellets and are also associated with human health impacts.

High density polyethylene (HDPE) was selected as a target material since it is one of the most used and recycled types of plastics today.[8] It can be used for similar products as virgin HDPE and products mentioned by producers and retailers of recycled HDPE include, for example, plastic pipes; plastic lumber for playgrounds, picnic tables, and outdoor patios; non-food bottles such as detergent containers, cleaning products, conditioners and shampoos; and children's toys.[9]

8 https://www.recyclingtoday.com/article/improving-hdpe-recycling/

9 Examples from https://www.letsrecycleit.eu/hdpe-recycling/; https://www.aaapolymer.com/hdpe-recycling/ ; https://www.plasticexpert.co.uk/plastic-recycling/hdpe-plastic-recycling/ accessed on November 12th, 2021.

**Mechanical recycling of plastics. Collected plastics are crushed, separated, washed, and shredded. Shredded plastic is melted and extruded through a hardening water bath. Plastic strings are chopped into nurdles and bagged for use. Production processes often emit uncontrolled waste into municipal water systems, landfills, or incinerators.**
Photos: ESDO, Bangladesh, CAG, India, and CEJ, Sri Lanka

# METHOD

A total of 24 bags of plastic pellets sold as high-density polyethylene (HDPE) were purchased for this study by IPEN NGO partners in 23 countries[10] from local recycling industries. In India, pellets were purchased from recycling facilities in two different cities.

The recycled pellets sampled were collected to provide a geographical diversity of the samples representing most regions of the world: Africa, Latin America, Asia, and Europe.

A random sample of pellets was taken from each bag and sent to the University of Chemistry and Technology Prague in the Czech Republic. From this sample, 2 grams was used for chemical analysis. The analysis targeted three groups of chemicals: brominated flame retardants, bisphenol A and benzotriazole UV stabilizers.

Details of the analytical methods and the results are provided in Annex I.

10 Argentina, Bangladesh, Cameroon, Congo, Egypt, India, Kazakhstan, Malaysia, Mauritius, Mexico, Nepal, Nigeria, the Philippines, Rwanda, Senegal, Serbia, Sri Lanka, Taiwan, Tanzania, Thailand, Ukraine, Vietnam, and Zambia.

The pellets were analyzed for presence of the following flame retardants:

The commercial mixtures of pentabromodiphenylether (PentaBDE), octabromodiphenylether (OctaBDE), and decabromodiphenylether (DecaBDE); hexabromocyclododecane (HBCD); decabromodiphenyl ethane (DBDPE); hexabromobenzene (HBB); pentabromoethylbenzene (PBEB); polybutylene terephthalate (PBT); tetrabromobisphenol A (TBBPA); BTBPE, and OBIND.

The pellets were analyzed for presence of the following benzotriazole UV stabilizers: UV-234, UV-326, UV-327, UV-328, UV-329, and UV-P.

Photo: Terre et Developpement, Cameroon


Photo: CEJ, Sri Lanka

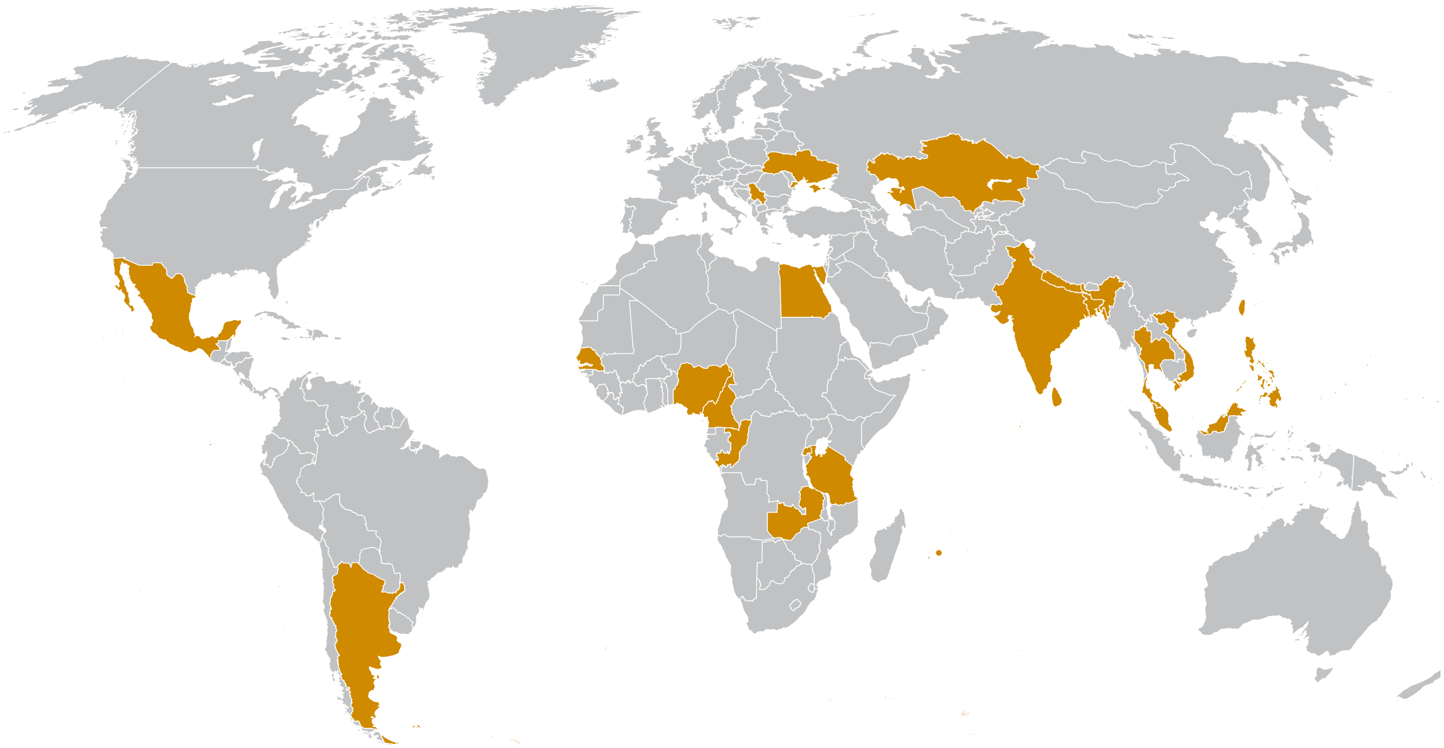

**Figure 1. Countries where pellets were purchased.**

**Photo: PANeM, Mauritius**

**Photo: ESDO, Bangladesh**

# RESULTS AND DISCUSSION

In total, the analyzes covered 18 chemicals added to plastic (counting the commercial mixtures of PentaBDE and OctaBDE as one each). Two samples contained 16 of these chemicals. Overall, more than half of the samples (54%) contained 11 or more chemicals (see Figure 2).

Out of the 24 analyzed pellet samples, 21 (88%) contained all three targeted groups of chemicals (see Figure 3.). One sample (4%) contained only one group of chemicals and 2 samples (8%) contained two groups of chemicals. None of the pellet samples were completely free from contamination by the targeted chemicals.

### SEVERAL TYPES OF PLASTICS INDICATED AS SOURCE MATERIAL FOR THE PELLETS

Out of the 24 samples, only the sample from Vietnam was free from contamination of brominated flame retardants and bisphenol A. This indicates that the waste materials in most cases were not properly sorted before recycling. Brominated flame retardants are used in Acrylonitrile Butadiene Styrene (ABS) or High-Impact Polystyrene (HIPS) plastics and Bisphenol A is commonly used to make polycarbonate plastic. None of these types of chemicals are commonly used in HDPE.

An effective technique used in many countries to separate different types of plastic is flotation/density separation. Bromine-treated plastics and polycarbonate have distinctly different densities than HDPE, which means that they will sink in freshwater where HDPE can float. This technique has for example been used successfully in the informal recycling sector in India (Haarman, 2016). However, the samples from India still contained all three types of chemicals, indicating that no such sorting was conducted.

The ability to sort the incoming plastics is also a matter of capacity and awareness at the facility. Considering the large amounts of plastic waste that is generated locally, in addition to any imported waste, sorting might be of lower priority than quickly feeding the incoming plastic into the process. Also, there might be a low level of awareness about toxic chemicals in plastics and the need to exclude plastics containing brominated flame retardants and bisphenol A among the recycling facility workers.

However, the cross-contamination between different types of plastics is a problem for recyclers in all countries and not only low- and middle-income countries. For example, in a recent study, contamination between different types of recycled polymers were seen even when purchasing the purest high-quality polyethylene and polypropylene recycled plastics from recycling companies located in Austria and Germany (Gall *et al.*, 2021).

### WIDESPREAD CHEMICAL CONTAMINATION IN THE PELLETS

Since there is no transparency about what chemicals are added to plastics during its production, it is difficult for recyclers without access to analytical instruments such as x-ray fluorescence spectrometers to determine what chemicals are present in the plastics going into the recycling process. This study shows that, as a result, chemical contamination of recycled plastic pellets is a widespread problem.

IPEN has previously, in a series of reports, shown that when recycling electronic waste containing brominated flame retardants, these toxic chemicals together with highly toxic brominated dioxins will end up in a range of consumer products, including kitchen utensils and toys (Budin *et al.*, 2020; Petrlik *et al.*, 2021; Strakova *et al.*, 2018). The results from this study show similar results for recycled plastic pellets. The most frequently detected brominated flame retardant was DecaBDE (22 samples), followed by its replacements DBDPE (18 samples) and OBIND (14 samples). It is notable that almost all pellet samples contained DecaBDE, since it was listed under the Stockholm Convention for global elimination in 2017 without any exemptions for recycling. 17 out of the 23 countries in this study have ratified this decision, including the two countries where DecaBDE was not detected.[11] The two chemicals, PentaBDE and OctaBDE, that were listed under the Stockholm Convention for global elimination in 2009 with exemptions for recycling were present at lower frequencies and lower levels, indicating that these obsolete flame retardants are finally on their way to be phased out from use.

11 Accessed on November 24th, 2021 http://chm.pops.int/Countries/StatusofRatifications/Amendmentstoannexes/tabid/3486/Default.aspx

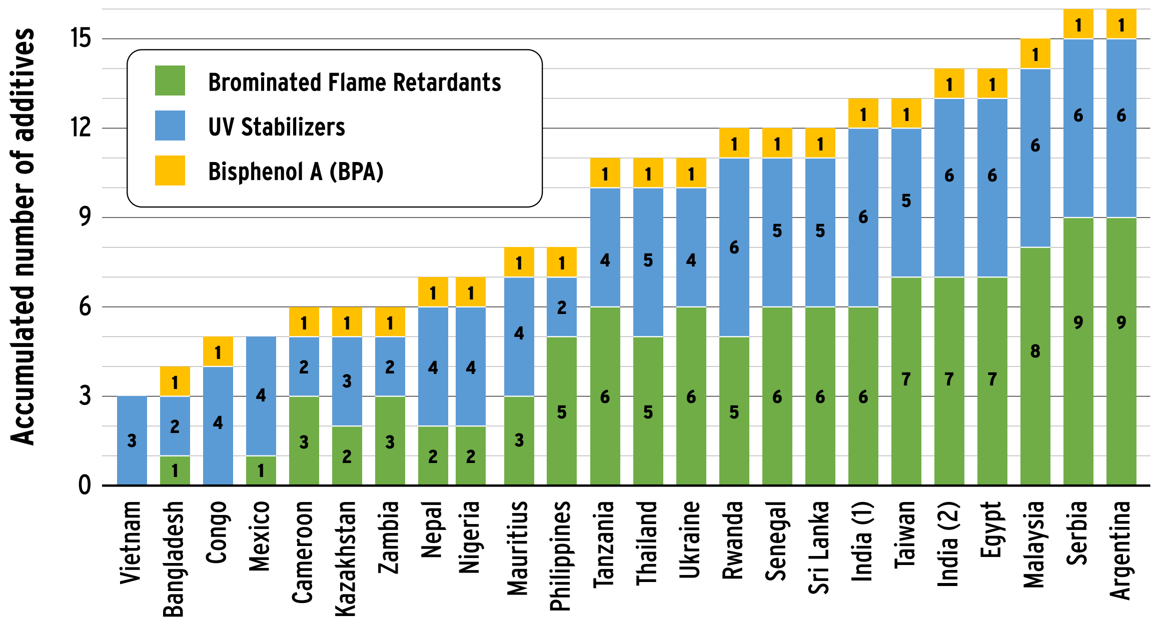


**Figure 2. Chemicals per sample. The numbers inside the bars show how many chemicals from each group was detected in each sample..**

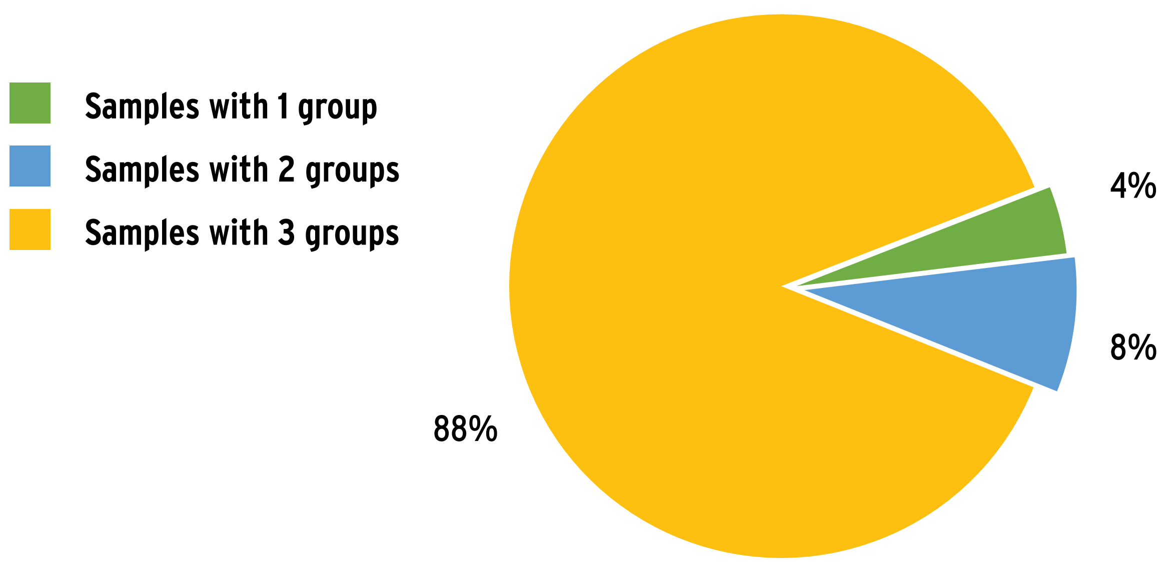


**Figure 3. Percentage of samples with chemicals from one, two, or three of the targeted groups.**

Bisphenol A was also detected in most (92%) of the samples despite being increasingly regulated in many countries because of its health impacts, especially on children. In addition, it is important to note the many benzotriazole UV stabilizers present in the pellets. While being high-volume industrial chemicals added to many types of plastics, they have only recently come under more thorough regulatory scrutiny. UV-328 is currently under evaluation by the Stockholm Convention POPs Review Committee, where it has been agreed that it meets the screening criteria of persistence, bioaccumulation, toxicity, and long-range transport to remote locations. It is the first chemical evaluated under the Convention where the primary mode of long-range transport is as a constituent of plastic debris.

This study was limited to three types of chemicals, but there are many other known toxic chemicals added to plastics such as phthalates, heavy metals, and chlorinated paraffins (McGrath *et al.*, 2021; Palacios-Arreola *et al.*, 2021; Strakova *et al.*, 2018). Evidence of widespread chemical contamination in recycled plastic has started to emerge over the past years and is increasing. Considering the number of plastic additives with known or suspected hazardous properties (Wiesinger *et al.*, 2021), there is cause for concern.

## THE HAZARDOUS CHEMICAL CONTENT RAISES CONCERNS FOR HEALTH IMPACTS

The three types of chemicals selected for this study can all cause harm to human health. There are scientific studies supporting the conclusion that bisphenol A (Flaws *et al.*, 2020), eight of the brominated flame retardants[12] (Dong *et al.*, 2021; Lu *et al.*, 2020; Lyche *et al.*, 2015; X. Wang *et al.*, 2019) and three of the UV stabilizers (UV-P, UV-329, and UV-328) (Sakuragi *et al.*, 2021) have endocrine-disrupting properties. However, there is too little information published about the remaining chemicals to draw any conclusion about their endocrine-disrupting properties. As shown in Figure 4, all samples contained at least two of the 12 known EDCs and most of the samples contained more than five.

In addition to their endocrine-disrupting potential, many of the chemicals have additional toxic properties. Looking at the most commonly detected substances in the recycled pellets, the polybrominated flame retardants such as DecaBDE are known to have neurotoxic properties (Hendriks *et al.*, 2015). There is also emerging evidence that newer brominated flame retardants, such as decabromodiphenylethane, share this property, in addition to its endocrine-disrupting properties (Jin *et al.*, 2018). There are also indications that DBDPE can cause adverse cardiovascular impacts (Jing *et al.*, 2019) and that BTBPE can cause cytotoxic effects in humans (Shi *et al.*, 2021).

Nineteen of the pellet samples contained UV-327, which is classified as a Substance of Very High Concern in the EU, requiring a specific authorization before use. Notifications provided by companies indicate that it may cause damage to organs, is harmful to aquatic life with long-lasting effects, causes serious eye irritation, causes skin irritation, and may cause respiratory irritation.[13]

Finally, there is little published information about the potential health impacts of several of the newer brominated flame retardants as well as the UV stabilizers, but their presence all raise concerns. All pellet samples contained the UV stabilizer UV-326 but very few studies have looked at its potential health impacts. There are, however, indications that it can impact gene expression related to inflammation and immune responses (Li *et al.*, 2019; Nagayoshi *et al.*, 2015).

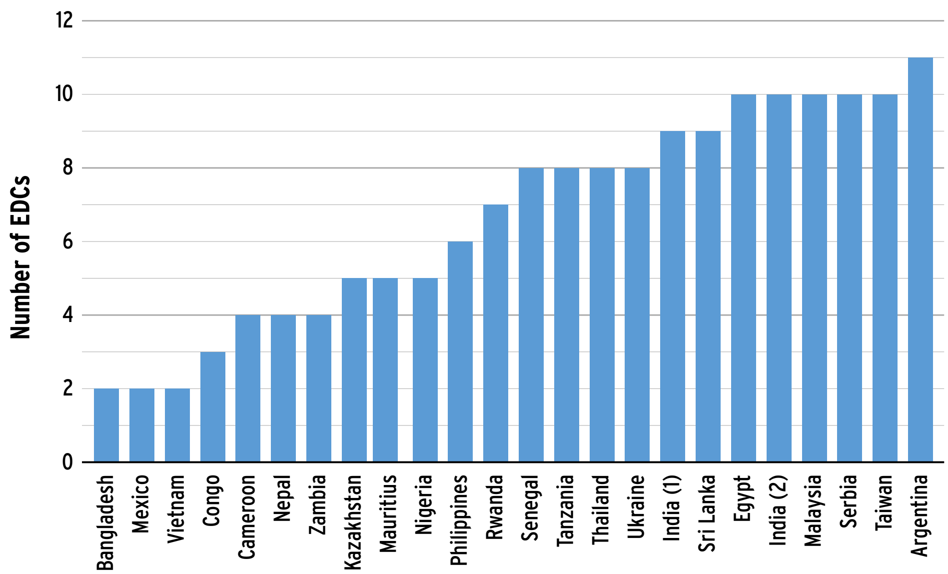


**Figure 4. Number of endocrine-disrupting chemicals per sample.**

The large number of toxic chemicals in many of the samples highlights the need to consider the potential for mixture effects. It is well documented that a mixture of endocrine-disrupting chemicals can cause a combined impact that is higher than just assessing the impact of each EDC in isolation (Kortenkamp, 2014). Noting the wide range of potential uses of the recycled pellets, including toys and plastic containers, these results raise concerns about potential health impacts and exposure of vulnerable populations such as children.

12 PentaBDE, OctaBDE, DecaBDE, HBCD, TBBPA, PBEB, BTBPE and DBDPE.

13 https://echa.europa.eu/sv/substance-information/-/substanceinfo/100.021.259

# CONCLUSION AND RECOMMENDATIONS

This study shows widespread contamination of recycled plastic pellets with toxic chemicals. It is likely that is in part due to the use of electronic waste and polycarbonate plastics as source materials, but also due to the widespread of use of toxic chemicals in plastics in general. These pellets are unacceptable for use as raw material when producing new products, especially products that can expose children to these chemicals.

The results of this study underscore the need to consider toxic chemicals in the light of a circular economy approach, and that the continued use of these will render most plastics in use today non-circular. The only way that this problem can be addressed is by strictly controlling what chemicals are allowed in plastics.

To stop toxic chemical additives in plastics damaging the circular economy, international agencies and policy makers should:

- Implement the same chemical safety rules to materials made with recycled plastics, as to those made from virgin plastics;
- Accelerate the phase-out of 'groups' of toxic chemicals, rather than taking a substance-by-substance approach;
- Use regulation to promote safe non-chemical alternatives that support the transition to a circular economy; and
- Halt the export of plastic waste containing toxic chemical additives, especially electronics.

Manufacturers should:

- Redesign products to allow for a toxics-free circular economy, including phasing out toxic chemical additives, and avoiding the use of alternatives that are known or suspected to be toxic; and
- List plastic ingredients, including additives, on labels and make the chemical content of plastics traceable throughout its life and waste stages.

Overall, governments should work towards decreasing the production of non-essential plastics, including ending subsidies for fossil fuel extraction and plastic production facilities. Global agreements should prevent the release of plastics into the environment.

# ANNEX 1 ANALYTICAL RESULTS

All concentrations are provided in µg/kg.

### BROMINATED FLAME RETARDANTS

There are three commercial mixtures of polybrominated flame retardants, named according to the average number of bromines attached to the diphenyl ether structure. The components of the commercial OctaBDE mixtures include the following congeners: BDE 153, 154, 183, 196, 197, 203, 206, and 207. The components of the commercial DecaBDE mixture are BDE 209, and HBCD includes 3 isomers; α-, β-, γ-HBCD.

The flame retardants were isolated by extraction with n-hexane : dichloromethane (4:1, v/v) and determined using gas chromatography coupled with mass spectrometry in negative ion chemical ionization mode (GC-MS-NICI). Identification and quantification of HBCD isomers were performed by liquid chromatography interfaced with tandem mass spectrometry with electrospray ionization in negative mode (UHPLC-MS/ MS-ESI-).

The limit of detection for PBDE 206, PBDE 207, PBDE 209, and OBIND was 1.0 µg/kg, for DBDPE 5.0 µg/kg, and for all the other 0.5 µg/kg.

| | Commercial mixture PentaBDE | | | | | | | Commercial mixture OctaBDE | | | | | | | | Deca-BDE | HBCD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | PBDE 28 | PBDE 47 | PBDE 49 | PBDE 66 | PBDE 85 | PBDE 99 | PBDE 100 | PBDE 153 | PBDE 154 | PBDE 183 | PBDE 196 | PBDE 197 | PBDE 203 | PBDE 206 | PBDE 207 | PBDE 209 | α-HBCD | β-HBCD | γ-HBCD | TBBPA | OBIND | PBEB | PBT | BTBPE | DBDPE | HBB |
| Argentina | * | * | 1.02 | * | * | * | * | 25.5 | * | 0.509 | * | * | * | 7.75 | 6.00 | 68.5 | 0.534 | * | * | 15.5 | 6.42 | * | * | 2.13 | 434 | * |
| Bangladesh | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 1.21 | * | * | * | * | * | * | * | * | * | * |
| Cameroon | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 2.00 | 14.7 | * | * | * | * | * | * | * | 1.87 | * | * |
| Congo | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| Egypt | * | * | * | * | * | * | * | 49.7 | * | 106 | 400 | 117 | 33.6 | 1136 | 815 | 12 283 | * | * | * | 477 | 545 | 1.43 | 5.26 | 298 | 4379 | 3.86 |
| India 1 | * | * | * | * | * | * | * | 5.29 | * | 4.78 | 3.12 | 3.96 | 0.764 | 27.7 | 27.2 | 382 | * | * | * | 15.6 | 3.45 | * | * | 17.7 | 288 | * |
| India 2 | * | * | 0.660 | * | * | * | * | * | * | 1.07 | 1.92 | 1.20 | 0.917 | 32.0 | 28.6 | 250 | * | * | * | 11.0 | 3.21 | * | * | 2.84 | 181 | * |
| Kazakhstan | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 1.38 | * | * | * | * | * | * | * | * | 42.3 | * |
| Malaysia | * | * | * | * | * | * | * | * | * | 2.36 | 16.7 | 7.40 | 6.64 | 351 | 235 | 2 103 | * | * | * | 6.22 | 1334 | 2.80 | 70.3 | 7.78 | 654 | 5.75 |
| Mauritius | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 26.5 | * | * | * | * | 4.51 | * | * | * | 133 | * |
| Mexico | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 3.40 | * | * | * | * | * | * | * | * | * | * |
| Nepal | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 19.1 | * | * | * | * | * | * | * | * | 15.6 | * |
| Nigeria | * | * | * | * | * | * | * | 0.842 | * | * | * | * | * | * | * | 2.88 | * | * | * | * | * | * | * | * | * | * |
| Philippines | * | * | * | * | * | * | * | 1.93 | * | 0.526 | 2.65 | 1.03 | 0.700 | 35.9 | 33.6 | 348 | * | * | * | 3.03 | 3.30 | * | * | * | 69.1 | * |
| Rwanda | * | * | * | * | * | * | * | 13.5 | * | * | * | * | * | 14.6 | 11.9 | 211 | * | * | * | * | 35.7 | * | 0.546 | * | 1515 | * |
| Senegal | * | * | * | * | * | * | * | 6.34 | * | 0.643 | 1.97 | 1.21 | 1.57 | 31.9 | 26.4 | 702 | * | * | * | 4.28 | 16.8 | * | * | 3.31 | 1102 | * |
| Serbia | * | * | * | * | * | * | * | 1.11 | * | 2.85 | 5.23 | 3.81 | 1.72 | 95.5 | 103 | 728 | * | * | * | 3.23 | 34.0 | 1.14 | * | 4.20 | 590 | * |
| Sri Lanka | * | * | * | * | * | * | * | 3.96 | * | 0.547 | 0.786 | 0.521 | * | 18.1 | 13.3 | 204 | * | * | * | 3.05 | 1.98 | * | * | 2.28 | 124 | * |
| Taiwan | * | 0.585 | * | * | * | 2.27 | * | 64.7 | * | 2.15 | 3.76 | 3.08 | 1.06 | 50.8 | 45.3 | 493 | * | * | * | 34.4 | 21.0 | * | * | 31.1 | 1201 | * |
| Tanzania | * | 0.743 | * | * | * | * | * | 5.91 | * | 1.03 | 1.13 | 0.952 | * | 34.4 | 27.9 | 675 | * | * | * | 2.41 | * | * | * | 2.77 | 42.4 | * |
| Thailand | * | * | * | * | * | * | * | * | * | 3.95 | 1.94 | 1.36 | * | 8.36 | * | 3.59 | * | * | * | * | 94.6 | * | * | 29.0 | 837 | * |
| Ukraine | * | * | * | * | * | * | * | 0.522 | * | * | * | * | * | 4.32 | * | 20.6 | * | * | * | 2.16 | 1.71 | * | * | 1.45 | 78.4 | * |
| Vietnam | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| Zambia | * | * | * | * | * | * | * | 3.43 | * | * | * | * | * | 4.82 | 2.68 | 28.2 | * | * | * | * | * | * | * | * | 47.0 | * |

** - Not detected*

### BISPHENOL A

Bisphenol A was extracted from the pellets using ultrasonic extraction with dichloromethane, and the concentration subsequently determined using ultra-high performance liquid chromatography-mass spectrometry/mass spectrometry (UHPLC-MS/MS).

The limit of detection was 1.25 µg/kg.

| Country | BPA |
|---|---|
| Argentina | 1,256 |
| Bangladesh | 60 |
| Cameroon | 178 |
| Congo | 5 |
| Egypt | 61,489 |
| India 1 | 10,367 |
| India 2 | 35,225 |
| Kazakhstan | 665 |
| Malaysia | 2,295 |
| Mauritius | 4,621 |
| Mexico | * |
| Nepal | 173 |
| Nigeria | 139 |
| Philippines | 172 |
| Rwanda | 126 |
| Senegal | 691 |
| Serbia | 19,755 |
| Sri Lanka | 226 |
| Taiwan | 994 |
| Tanzania | 742 |
| Thailand | 1,090 |
| Ukraine | 478 |
| Vietnam | * |
| Zambia | 859 |

** - Not detected*

### UV STABILIZERS

The UV stabilizers were extracted from the pellets using ultrasonic extraction with dichloromethane, and the concentrations subsequently determined using ultra-high performance liquid chromatography-mass spectrometry/mass spectrometry (UHPLC-MS/MS).

Limit of detection for UV-234, 326 and 327 was 0.01 µg/kg; for UV-328 0.03 µg/kg and for UV-P 0.1 µg/kg.

| Country | UV-234 | UV-326 | UV-327 | UV-328 | UV-329 | UV-P |
|---|---|---|---|---|---|---|
| Argentina | 18.6 | 1,724 | 546 | 92.0 | 5.64 | 3.36 |
| Bangladesh | * | 1.42 | 0.070 | * | * | * |
| Cameroon | * | 0.258 | 0.393 | * | * | * |
| Congo | * | 83,228 | 56,178 | * | 9,552 | 560 |
| Egypt | 498 | 4,788 | 1,012 | 334 | 1,950 | 699 |
| India 1 | 72.7 | 1,309 | 18.4 | 6.57 | 3.98 | 384 |
| India 2 | 10.7 | 165 | 376 | 15.7 | 157 | 37.1 |
| Kazakhstan | * | 1,546 | * | * | * | 76.4 |
| Malaysia | 9.62 | 1,105 | 215 | 39.3 | 3.91 | 185 |
| Mauritius | * | 821 | 427 | 10.9 | 1.65 | * |
| Mexico | 0.225 | 3.82 | 3.54 | 0.365 | * | * |
| Nepal | 1.69 | 313 | 4.93 | 1.66 | * | * |
| Nigeria | * | 427 | 48.0 | 1.63 | 1.03 | * |
| Philippines | * | 4,877 | * | * | 173 | * |
| Rwanda | 1.42 | 318 | 212 | 19.9 | 0.654 | 0.344 |
| Senegal | 27.5 | 344 | 121 | 2.20 | 3.29 | * |
| Serbia | 5.50 | 906 | 10.7 | 0.102 | 1.17 | 7.65 |
| Sri Lanka | * | 758 | 86.1 | 101 | 7.79 | 99.6 |
| Taiwan | * | 3,511 | 165 | 66.2 | 11.4 | 97.0 |
| Tanzania | 0.496 | 1,115 | 129 | 1.81 | * | * |
| Thailand | 23.8 | 1,069 | * | 87.3 | 124 | 216 |
| Ukraine | 43.0 | 14,638 | * | 21.0 | * | 82.2 |
| Vietnam | * | 11,769 | * | * | * | 22.9 |
| Zambia | * | 1,667 | 39.7 | * | * | * |

** - Not detected*

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