Toxic Contamination Caused by Plastic Waste in Countries of the Global South

Jindrich Petrlik, Bjorn Beeler, Yuyun Ismawati, and Lee Bell

Introduction

The enormous amounts of plastic waste transferred from developed to developing countries are an environmental problem because the transferred waste is difficult to handle. Plastics contain various chemical additives which make these wastes hard to easily destroy or recycle (Marine Litter Topic Group, 2019). We must also consider plastics from used electronics, in addition to waste from plastic packaging and general consumer products. Plastics used in electronics contain high levels of flame retardants, including ones which are banned or listed under the Stockholm Convention on persistent organic pollutants (POPs), such as polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), or dechlorane plus (DP). The same applies to wrecked cars also often ending on scrap yards in developing countries as they contain many plastics with high concentrations of hazardous flame retardants and other chemical additives.

However, there are many chemicals in plastics which are not followed with same level of concern as the additives in electronics or cars. A recent study identified "more than 10,000 relevant substances" in plastics and categorized them "based on substance types, use patterns, and hazard classifications wherever possible" (Wiesinger et al., 2021). Over 2400 substances were identified as "substances of

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potential concern as they meet one or more of the persistence, bioaccumulation, and toxicity criteria in the European Union." The study also found that many of these substances (1327) "are not adequately regulated in many parts of the world" or are even "approved for use in food-contact plastics in some jurisdictions (901 substances)" (Wiesinger et al., 2021). Looking at pictures from plastic waste yards in Indonesia (see Photos 3, 4, and 5), Malaysia, or Turkey, we can identify plastic packaging in which a large number of these unregulated chemicals can be found.

A report published by UNEP identified even higher number of chemicals in relation to plastics: "More than 13,000 chemicals are associated with plastics and plastic production across a wide range of applications, of which over 3,200 monomers, additives, processing aids and non-intentionally added substances are of potential concern due to their hazardous properties. These properties include carcinogenicity, mutagenicity, reproductive toxicity, specific target organ toxicity, endocrine disruption, ecotoxicity, bioaccumulation potential, environmental persistence and mobility, including potential for long-range environmental transport to remote locations" (Weber et al., 2023).

Plastic waste is transferred to the Global South, including all the toxic additives in it. As most developing countries do not have appropriate disposal technologies, plastic waste, including automotive and electronic waste, ends at large scrap yards or dumpsites where it is often destroyed by open burning to get metals from it or simply to reclaim more space for new loads of plastic wastes (Gündoğdu, 2022; Petrlik et al., 2020a; Velis & Cook, 2021). This practice leads to the creation of even larger numbers of toxic chemicals released in the environment and affecting the health of communities in developing countries. One of the highest burdens is caused by burning plastics from electronic or automotive waste as the presence of metals in this process increases the creation of very toxic dioxins[1] (PCDD/Fs). This activity is also listed as one of major sources of unintentionally produced POPs (UPOPs) under the name "smoldering copper cables" (see Fig. 2) in Annex C to the Stockholm Convention (SC, 2009; Stockholm Convention, 2008).

Flows of various toxic chemicals in plastics may vary. Figure 1 illustrates such global flows for PBDEs and transfer of their emissions from developed to developing countries that was published in a recent study on unequal ecological exchange (Tong et al., 2022).

The International Pollutants Elimination Network (IPEN) and its member organizations carried out several studies mapping food chain contamination with toxic chemical releases, most likely from dumped plastic wastes or their burning, at a number of sites affected by these disposal practices mostly in developing or transition countries. These studies focused mainly on POP levels in free-range chicken eggs. They were summarized in a global report showing significant levels of POPs at 25 sites affected by plastic waste disposal in 14 countries around the globe (Petrlik

[1] Dioxins are a large group of unintentionally produced POPs of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). They are listed under Stockholm Convention in Annex C. This term also includes often another group of dioxin-like polychlorinated biphenyls (dl PCBs). We will use the acronym PCDD/Fs in our text.

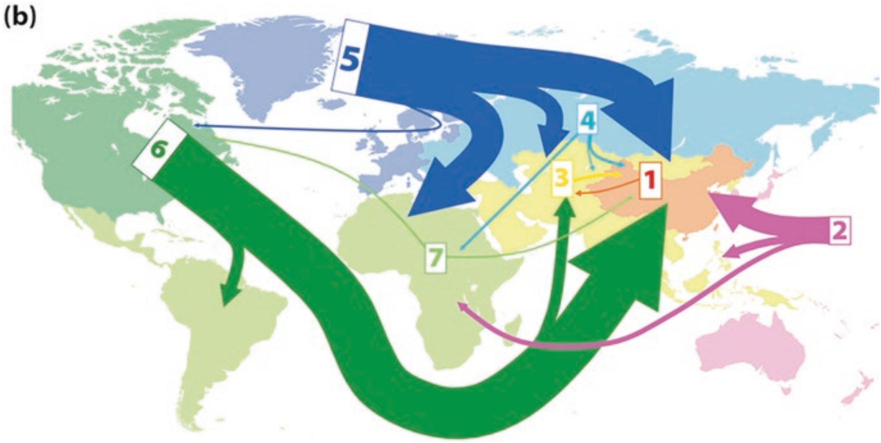

Fig. 1 Illustration of the flows of the trade embodied emissions of PBDEs between the world regions. (Source: Tong et al. (2022))

Photo 1 Typical example of smoldering copper cables at an e-waste scrap yard in Agbogbloshie, Ghana. (Photo: Martin Holzknecht (Arnika))

et al., 2021). A wide range of POPs was observed in free-range eggs from sites affected by disposal of plastic waste in Asia, Africa, Latin America, and Europe (Photo 1).

Free-range chicken eggs are sensitive indicators of POP contamination in soils/dust and represent an important human exposure pathway (Piskorska-Pliszczynska et al., 2014; Van Eijkeren et al., 2006). As "active samplers," they can be used to reveal POP contamination, particularly in areas impacted by PCDD/Fs and PCBs

(Arkenbout & Bouman, 2021; Aslan et al., 2010; DiGangi & Petrlik, 2005), as well as by brominated flame retardants (BFRs) (Petrlik et al., 2017; Polder et al., 2016) or brominated dioxins (PBDD/Fs) (Teebthaisong et al., 2021; Weber et al., 2015).

It is well established that toxic chemicals are released into the environment not only during the production and the use of plastics (Karlsson et al., 2021; Møller et al., 2020) but also during their disposal (BC & SC Secretariat, 2019; Hahladakis et al., 2018), in particular when burning or incineration is involved (Blankenship et al., 1994; Stockholm Convention, 2008).

It is not only dumping and open burning (Velis & Cook, 2021) of imported plastic waste that affects communities in Global South. In several places, local people found plastic waste to be a good fuel replacing the use of wood, but burning plastic as fuel produces a much wider range of toxic pollutants such as polychlorinated or polybrominated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs and PBDD/Fs) as well as dioxin-like polychlorinated biphenyls (dl PCBs) or polycyclic aromatic hydrocarbons (PAHs). For example, in Tropodo, Indonesia (see Photo 2), imported plastic waste was used as fuel in tofu production facilities (Ismawati Drwiega et al., 2019). In Karawang, Indonesia, plastic waste is used as fuel in kilns for chalk production. At both places, high levels of dioxins were measured in free-range chicken eggs (Petrlik et al., 2022b, d).

Off-gases from facilities like tofu factories or chalk kilns are not the only sources of contamination as ashes produced by burning of plastics also contain dioxins and furans. The ashes contained up to 1.2 and 0.5 ng TEQ/g of PCDD/Fs in Tropodo and Karawang, respectively, yet they were not considered as being hazardous due to a loophole in international legislation which defines dioxin POP waste as hazardous only above a level of 15 ng TEQ/g PCDD/Fs. The ashes are widely repurposed for

Photo 2 Tofu factories burning plastic waste as fuel in Tropodo, Indonesia, as documented in November 2019. (Photo: Jindrich Petrlik (Arnika))

Photo 3 Plastic waste yard in Bangun, Indonesia, in 2019. (Photo: Fully Syafi (Ecoton))

Photos 4 and 5 Evidence of the origin of plastic packaging waste imported to Bangun, Indonesia, from the United Kingdom; November 2019. (Photo: Jindrich Petrlik (Arnika/IPEN))

construction of roads and public pathways or for embankments in these localities. Free-range hens can access these areas and become contaminated with PCDD/Fs or other POPs contained in ashes (Katima et al., 2018; Petrlik et al., 2020a). The ash from waste incineration is suggested by authorities to be used as soil amendment in

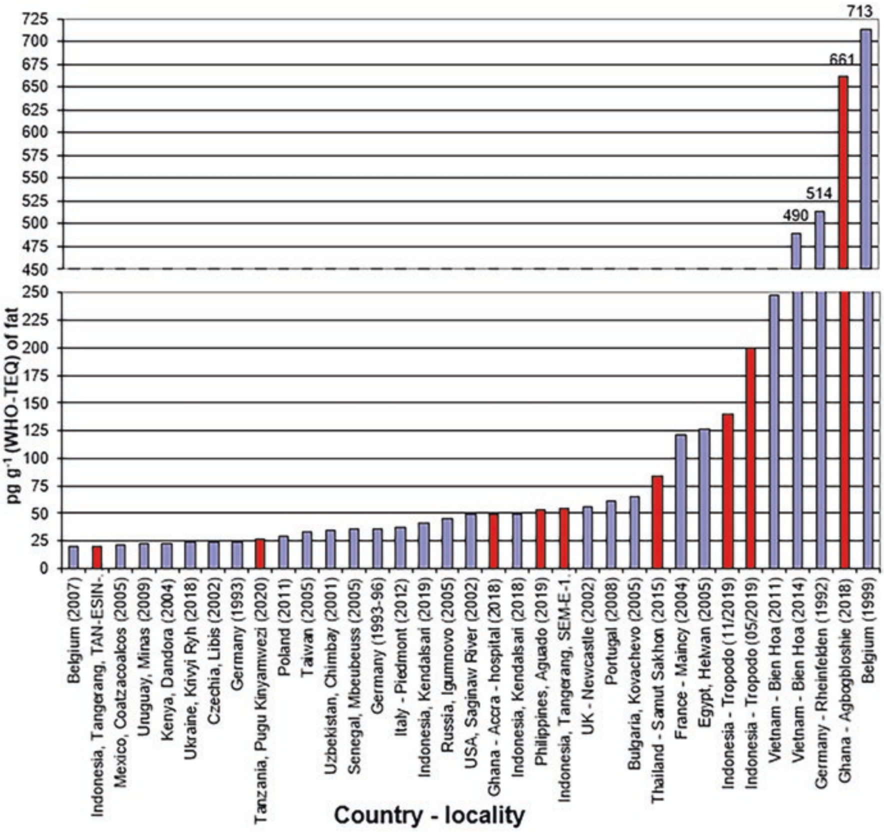

Fig. 2 Highest levels of PCDD/Fs measured globally in chicken eggs until 2020. Red bars show samples from sites affected by plastic waste disposal included in IPEN's report. (Source: Petrlik et al. (2021))

some developing countries (Dzonteu, 2020; Mochungong et al., 2012; Wang et al., 2008). This suggestion does not consider the high levels of PCDD/Fs and other POPs in waste incineration residues as consequence of burning plastics and how they will lead to soil and food chain contamination.

It was estimated that 53.6 million metric tons (Mt) of e-waste from consumer products alone were generated in 2019, and it is predicted to exceed 74 Mt by 2030 (Forti et al., 2020). An estimated 70–80% of e-waste was shipped from developed to low-income countries and was improperly recycled (Ádám et al., 2021; Forti et al., 2020). This also includes plastic casings and other plastic parts of e-waste, mostly treated with flame retardants including brominated or chlorinated compounds currently banned and listed under the Stockholm Convention (Stockholm Convention, 2009a, b, 2013, 2017, 2023), although they are contained in used electronic products produced in the years when the ban of some BFRs was still pending. Electronic waste was spotted at some sites included in IPEN's global study, like

Indonesia or Uruguay, and the report included one of the largest e-waste and automotive waste scrap yard in Agbogbloshie, Ghana, where high levels of PBDEs were measured in soils (Akortia et al., 2017). The highest ever measured levels of 661 and 300 pg TEQ/g fat of chlorinated and brominated dioxins (PCDD/Fs and PBDD/Fs), respectively, in free-range chicken eggs globally were found in samples from this scrap yard (Hogarh et al., 2019). High levels of PCDD/Fs, dl PCBs, and PBDD/Fs were also observed in free-range chicken eggs from the vicinity of other e-waste sites located in developing countries (Petrlik et al., 2022b; Zeng et al., 2018).

An adult eating just 1 egg from a free-range chicken foraging in Agbogbloshie area would exceed the European Food Safety Authority (EFSA) tolerable daily intake (TDI) at level of 0.25 pg WHO-TEQ/kg of body weight/day for dioxins (EFSA CONTAM, 2018a) by 220-fold. Indicator PCBs in these eggs were four-fold higher than the EU standard, and dioxins and dioxin-like PCBs were 171-fold higher than the standard (European Commission, 2016).

High levels of POPs, dioxins, and PBDEs in particular were also measured in samples of soil, dust, and hair from Guiyu, an e-waste site in China (Luksemburg et al., 2002; Xu et al., 2017). Also, rice hulls from the vicinity of another e-waste site in China contained relative high levels of PCDD/Fs, PCBs, and PBDEs (Fu et al., 2012).

Figure 2 shows that among the highest levels of PCDD/Fs measured globally in chicken eggs are more samples from the sites with plastic and/or electronic waste disposal, including Tropodo (Indonesia), Samut Sakhon (Thailand), and others.

A wide range of analyses was conducted at five dumping sites in Adana province, Turkey, where plastic waste imported mainly from the European Union and the United Kingdom was illegally dumped and burned (Gündoğdu, 2022). In comparison with the control samples, the concentrations of PCDD/Fs determined in the survey areas were found to be "approximately 400,000 times higher in Yüreğir/İncirlik field and 8000 times in Seyhan/Yenidam field. … The concentration of polycyclic aromatic hydrocarbons (PAHs) determined in the soil samples collected from Yenidam was up to 35 times higher than the concentration of PAHs reported in previous studies of other regions in Turkey" (Gündoğdu, 2022). PAHs are common pollutants occurring at sites of open burning of plastics (Velis & Cook, 2021), and plastic waste itself can contain them (Conesa et al., 2021) because plastic is mainly produced from oil.

Chinese scientists focused on heavy metal contamination at a typical plastic recycling site in North China and found that "the surface soils and sediments have suffered from moderate to high metal pollution and in particular, high Cd and Hg pollution" and "that there is considerable to high potential ecological risks in more than half of the soils and high potential ecological risk in almost all sediments" (Tang et al., 2015). Source assessment suggested that heavy metals in soils and sediments were mainly derived from inputs from poorly controlled plastic waste recycling in this area. High levels of heavy metals were observed also at the previously mentioned five sites in Adana province, Turkey (Gündoğdu, 2022).

It must be noticed that plastic recycling in areas in Southeast Asia is mostly turned to large plastic waste scrap yards like the one in Bangun, Indonesia (see Photo 3).

Intentionally produced POPs used as additives in plastics were measured in high levels in free-range chicken eggs from the sites affected by plastic waste disposal along with dioxins. The level of 27,159 ng/g fat of PBDEs in free-range eggs from Tropodo was the second highest level ever measured in eggs right after the level of 46,000 ng/g fat in eggs from e-waste site in Guiyu, China. High levels were measured also in other samples from the vicinity of the sites affected by plastic waste disposal, including Bangun, Indonesia, with a large plastic waste scrap yard or Taizhou (Labunska et al., 2013), another e-waste site in China (see graph at Fig. 3).

The egg samples from the Bangun waste yard, known for large quantities of imported plastic waste (Ismawati et al., 2019), have also shown levels of per- and polyfluorinated compounds (PFASs) comparable to the sites affected by industry from Western Europe (Petrlik et al., 2020a). An adult eating half an egg per day from a free-range chicken foraging in the vicinity of the Bangun dumpsite would exceed the proposed tolerable daily intake (TDI) of PFOS (EFSA CONTAM, 2018b) up to almost 16-fold (Petrlik et al., 2020a).

PFASs are known to contaminate drinking water source near industrial and military sites (Hu et al., 2016; Post et al., 2012). A study conducted in the vicinity of waste disposal sites, including plastic wastes in Thailand, demonstrated "that waste disposal site leachates represent a likely major PFAS source in groundwater in Thailand" (Hongkachok et al., 2023). Thailand became one the key destinations of electronic and plastic waste exports in Southeast Asia, after China closed its doors to mixed plastic waste imports in 2017 (Petrlik et al., 2022c; Roberts-Davis & Saetang, 2019).

The occurrence of short and medium chain chlorinated paraffins (SCCPs and MCCPs) and dechloranes, also additives to plastics, was confirmed in free-range chicken eggs and soil collected near waste disposal sites in Tanzania in a recent study (Haarr et al., 2023), which confirmed results for SCCPs in eggs from previous research by IPEN (Petrlik et al., 2020b). The study concluded, "risk assessment of CPs shows that consumption of eggs from free-range chickens could represent a health concern regarding exposure to SCCPs" (Haarr et al., 2023) (Photos 4 and 5).

POPs analyzed in soil, eggs, rice, and other locally grown food from the sites affected by imported plastic waste, including plastic in electronic and automotive waste, have serious impacts on human health. BFRs such as PBDEs are known endocrine-disrupting chemicals (EDCs) and adversely impact the development of the nervous system and of children's intelligence (POP RC, 2006, 2007, 2014).

Per- and polyfluoroalkyl substances (PFASs) are a large class of more than 4500 (OECD, 2018) very persistent fluorinated chemicals (including PFOS) that have been widely used in packaging, textiles, and other plastics. Scientists are concerned with their widespread presence in the environment, and the Madrid Statement said that they "call on the international community to cooperate in limiting the production and use of PFASs and in developing safer nonfluorinated alternatives" (Blum et al., 2015). In animal studies, some long-chain PFASs have been found to cause

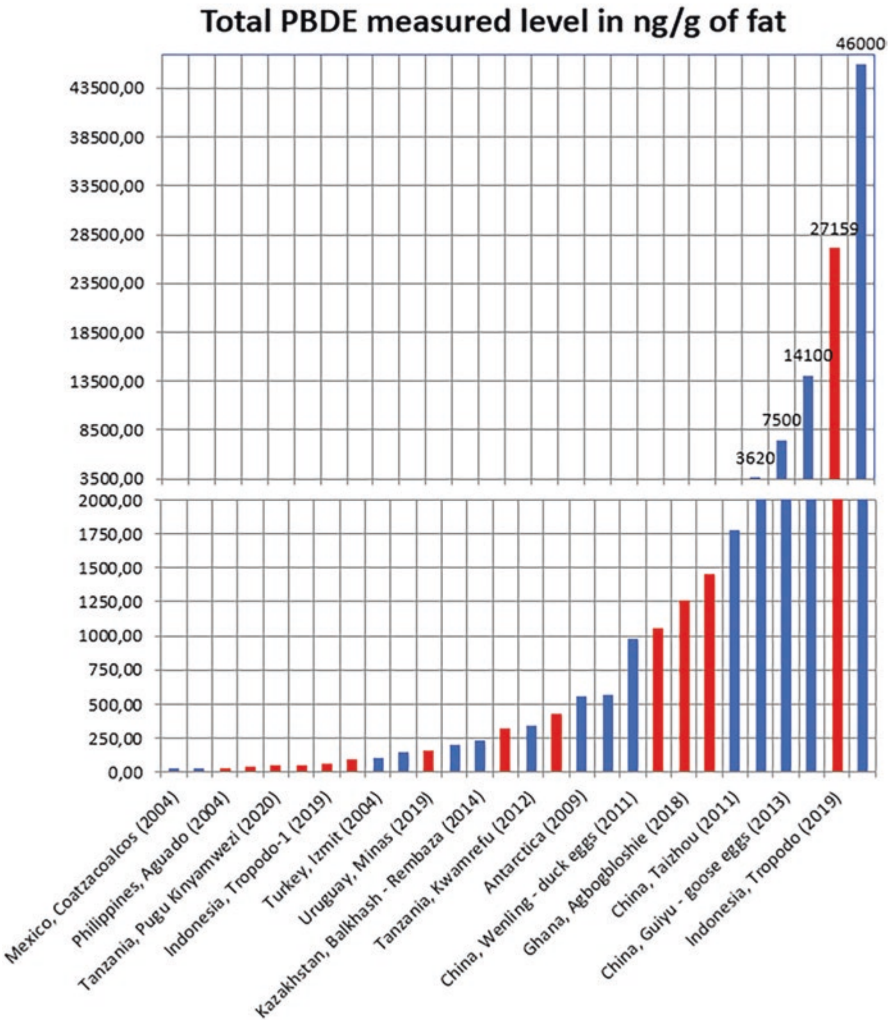

Fig. 3 The highest levels of PBDEs measured globally in chicken eggs until 2020. Red bars show samples from sites affected by plastic waste disposal included in IPEN's report. (Source: Petrlik et al. (2021))

liver toxicity, disruption of lipid metabolism and of the immune and endocrine systems, adverse neurobehavioral effects, neonatal toxicity and death, and tumors in multiple organ systems (Lau et al., 2007; Post et al., 2012). More health effects of this very large group of chemicals are summarized in the Madrid and Zurich statements as well as in the toxicological profiles of PFASs (ATSDR, 2018; Blum et al., 2015; Fenton, 2019; Ritscher et al., 2018).

Chlorinated dioxins (PCDD/Fs) are known to be extremely toxic. Numerous epidemiologic studies have revealed a variety of human health effects linked to dioxin exposure including cardiovascular disease, diabetes, cancer, porphyria, endometriosis, early menopause, alteration of testosterone and thyroid hormones, and altered immune system response among others (Schecter, 2012; White & Birnbaum, 2009). Laboratory animals given dioxins suffered a variety of effects, including an increase in birth defects and stillbirths. Food (particularly from animals) is the major source of dioxin exposure for humans (BRS, 2017).

PBDD/Fs have been found to exhibit similar toxicity and health effects as their chlorinated analogs (PCDD/Fs) (Behnisch et al., 2003). They can, for example, affect brain development, damage the immune system and fetus, or induce carcinogenesis (Kannan et al., 2012).

Exposure to chemicals contained in consumer products such as toys, hair accessories, and/or kitchen utensils (Kuang et al., 2018; Møller et al., 2021; Samsonek & Puype, 2013; Strakova & Petrlik, 2017) made of recycled plastic from used electronics and cars is additional burden to human health globally, including developing countries. A recent study has shown widespread occurrence of products contaminated with BFRs obtained at markets from African and Arabic countries (Petrlik et al., 2022a), and a similar situation was previously found in products from a wide range of other developing countries (DiGangi & Strakova, 2016).

POPs and heavy metals represent the groups of chemicals brought in imported plastics from the Global North to the Global South. UPOPs are created by insufficient plastic waste management as a result of the widely ignored fact that developing countries lack proper technologies for disposal of plastic waste while acknowledging that for wide range of plastics, such technologies do not exist anywhere at this time.

We have not discussed the other toxic chemical effects of plastics or contamination with other additives such as phthalates or bisphenol A in this chapter yet. The levels of phthalates found increased in the vicinity of some dumpsites in South Africa (Adeniyi et al., 2008). Another study based on research in six Asian developing countries suggested that microplastics “could be potential sources of the phthalates and brominated retardants” in soils at dumpsites (Tun et al., 2022). These toxic chemicals’ effects were demonstrated in numerous studies (Fantke et al., 2021; Groh, 2019; Marine Litter Topic Group, 2019; Verma et al., 2016).

Plastic waste management remains challenging mainly from the point of view of potentially toxic substances in plastics. It was well documented on PBDEs: “Since the largest proportion of interregional PBDE emission transfer arises from the waste disposal stage, global efforts aiming to address the issue of the ecological unequal exchange and reduce the health and environmental impacts of PBDEs should focus on tackling the problem of e-waste trade. Since countries in the developed regions often have higher labor costs and more stringent environmental regulations, a large proportion of their wastes are exported to other, often less developed countries” (Tong et al., 2022).

Minimization of use of plastics remains the primary solution to this problem alongside phasing out of toxic additives in plastics and phasing out of the most problematic plastics such as PVC in relation to UPOPs generated during their disposal. It is also necessary to set more strict limits to control POPs (Weber et al., 2019) and heavy metal content in the wastes in order to halt their free movement across borders. The Stockholm Convention could apply material substitution[2] much more rigorously to avoid UPOP releases.

The plastic waste crisis including the spread of toxic chemicals related to the production, use, and disposal of plastics is accelerating and requires immediate action. Unfortunately, the most severe consequences will be felt in developing countries as more recent studies demonstrate. One study suggests that "the strategies that are appropriate for OECD nations are not always appropriate for developing economies" (Browning et al., 2021). Locally focused approaches like "Locally Managed Decentralized Circular Economy (LMDCE) provide the best option for addressing the problem of mismanaged and unmanaged plastic waste in infrastructure limited countries and has the potential to be transformative for both women and men" (Browning et al., 2021).

Increasing volumes of plastic waste and toxic chemical releases globally led to the conclusion "that humanity is currently operating outside the planetary boundary" (Persson et al., 2022). "The increasing rate of production and releases of larger volumes and higher numbers of novel entities with diverse risk potentials exceed societies' ability to conduct safety related assessments and monitoring," stated scientists in the global assessment in 2022 (Persson et al., 2022). The new global treaty on plastic waste must therefore also address toxic pollution caused by plastic overuse and overproduction. Developing countries should not serve as dumping grounds for plastic waste collected worldwide.

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[2] Part V, Annex C, of the Stockholm Convention names the following measure among the general prevention measures relating to both best available techniques and best environmental practices: "Replacement of feed materials which are persistent organic pollutants or where there is a direct link between the materials and releases of persistent organic pollutants from the source."

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