UNITED NATIONS

UNEP/EA.7/INF/10

United Nations Environment Programme

UNEP

Distr.: General
19 November 2025

Original: English

United Nations Environment Assembly
of the United Nations Environment Programme
Seventh session
Nairobi, 8–12 December 2025
Item 5 of the provisional agenda

International environmental policy and governance issues

Information on the implementation of resolution 6/9 on sound management of chemicals and waste to address lead, cadmium, arsenic, and organotins*

Note by the secretariat

1. In paragraph 8 of resolution 6/9 on the sound management of chemicals and waste, the United Nations Environment Assembly of the United Nations Environment Programme (UNEP) requested the Executive Director of UNEP to prepare a report, subject to the availability of resources, building on existing measures and initiatives to address lead, cadmium, arsenic and organotins.

2. In response to this request, UNEP developed a report on options to address lead, cadmium, arsenic, and organotins pollution, which is presented in the annex to the present note. The report synthesizes findings from UNEP's previous assessments, stakeholder consultations and recent scientific literature. Drawing on these findings, it highlights the need for a life-cycle approach that addresses pollution risks from supply and demand, intentional and unintentional sources, and sector-specific challenges, as well as the importance of globally coordinated strategies. The report then explores practical solution pathways for a step-wise approach, and lays down a range of policy options to guide and coordinate action on pollution reduction.

* The document has not been formally edited.

Report on options to address lead, cadmium, arsenic, and organotins pollution

Executive Summary

The urgent global exposure risks posed by toxic metals and metalloids[1] – lead, cadmium, arsenic, and organotins – remain inadequately addressed. These substances have well-documented impacts on human health and ecosystems, even at low levels of exposure. They are linked to irreversible neurodevelopmental damage (Larsen and Sánchez-Triana, 2023), cancer (Oberoi et al., 2014; UNEP, 2010b; Gibb et al., 2019), endocrine disruption (Rana, 2014; Sabir et al., 2019), kidney disease (UNEP, 2010b; Gibb et al., 2019) and cardiovascular disease (Chowdhury et al., 2018; Lamas et al., 2023). They have also been associated with antimicrobial resistance (Gillieatt and Voleman, 2024; Balta et al., 2025), among other effects. Additional traits such as persistence (UNEP, 2020b), bioaccumulation (Huang et al., 2025), and long-range transport (He et al., 2023; Grotti et al., 2024) exacerbate concerns about their presence in the environment, with disproportionate burdens falling on children and vulnerable populations in low- and middle-income countries (Ericson et al., 2021; Heng et al., 2022; Sripada et Lager, 2022). For these reasons, the UN Environment Assembly asked the United Nations Environment Programme (UNEP) to review this situation and present this report.

While there are many sources of metals and metalloids, it is important to distinguish between the presence of a source and exposure at levels that may cause harm. In the absence of exposure, no environmental or human health impacts occur; therefore, efforts to prevent exposure remain imperative.

Despite decades of international attention, current measures are fragmented and insufficient to cover the full scope of global risks associated with exposure to these metals. Existing instruments tend to focus on specific substances, uses or life cycle stages – such as lead in gasoline or organotins in ship coatings – leaving major sources like informal recycling, industrial emissions and contaminated consumer products largely unregulated. The result is widespread exposure through soil, air, water and food, with significant and growing implications for public health and its associated economic costs, environmental integrity, and economic development.

The issues of environmental and human health exposure are compounded by rising production and consumption when pollution risk reduction does not accompany these growth trends. For example, the global demand for refined lead, cadmium and arsenic has increased significantly over the past two decades (IEA, 2021; OECD, 2023; USGS, 2025a,b,c). Recent estimates suggest that over 1.5 million premature deaths and more than 34 million disability-adjusted life years (DALYs) were attributable to lead, cadmium and arsenic exposure in 2021 alone (IHME, 2024). Lead exposure is estimated to cost the global economy US$6 trillion annually, primarily through IQ loss and cardiovascular mortality (Larsen et Sánchez-Triana, 2023).

These figures likely underestimate the true burden, as many exposure pathways and societal costs remain unquantified. For example, cadmium and arsenic assessments have focused narrowly on occupational and food borne exposure. Organotins may be released during production; through use, such as direct releases from pesticides, and leaching from ship hulls and PVC piping; and disposal, such as from landfills, through the removal of old organotin paint from ships during maintenance, and through leaching from PVC microplastics (Fent, 1996a,b; Rantakokko et al. 2006; Guerin et al., 2007; Santos et al., 2009; Airaksinen et al., 2010; Choi et al., 2012; Krupp et al., 2010; Yi et al., 2012; Sousa et al., 2014). Informal recycling of lead-acid batteries continues to expose millions to dangerous levels

[1] For the purposes of this report, the term "metals" is used in a broad sense to encompass heavy metals (such as lead and cadmium), metalloids (such as arsenic), and organometallic compounds (such as organotins) that contain metal elements and are used in various industrial and consumer applications.

of lead, especially in countries lacking adequate infrastructure and enforcement of safe recycling methods (UNEP, 2020a; Ericson et al. 2016). Meanwhile, contaminated soils threaten food safety and agricultural productivity, with cadmium and arsenic levels exceeding internationally recognized thresholds in crop areas across Asia, Africa, and Latin America, thus damaging safe deliver of food security (Rosas-Castor et al., 2014; FAO and ITPS, 2015; Rashid et al., 2023; Hou et al., 2025).

This report synthesizes findings from UNEP's previous assessments, stakeholder consultations and recent scientific literature to establish a compelling case for enhanced international action. It highlights the need for a **life-cycle approach** that addresses pollution risks from supply and demand, intentional and unintentional sources, and sector-specific challenges. It also emphasizes the importance of **globally coordinated strategies**, given the transboundary nature of emissions, trade and waste flows.

The report further explores practical solution pathways for a step-wise approach, highlighting where countries and stakeholders can take near-term action to address major sources, reflecting economic realities and sector-specific risks. It lays down a range of policy options, from legally binding instruments and high-level political declarations, supported by a global plan and targets, to nationally driven regulations, voluntary partnerships, non-binding/soft law arrangements such as government-led codes of conduct to voluntary industry-led measures. It underscores the availability of technically feasible and economically viable alternatives for many uses, and the potential for integrated, multi-pollutant reduction and control strategies to deliver co-benefits across sectors. Lessons from the successful phase-out of leaded gasoline and the implementation of the Minamata Convention on Mercury offer valuable insights for designing effective responses.

Efforts to address pollution and toxic emissions encompass a wide range of sectors and sources. The **mining and smelting** industries are significant contributors to environmental contamination, often releasing heavy metals and other pollutants into surrounding ecosystems (Zeng et al., 2021; Qi et al., 2023; Shao et al., 2025). Similarly, **informal recycling activities**, such as the recovery of materials from used lead-acid batteries and electronic waste (e-waste), when not done with safety considerations in place, pose serious health and environmental risks due to the unsafe handling of hazardous substances (Haefliger et al., 2009; UNEP, 2020a).

The **energy and industrial combustion** sectors can also be major sources of air pollution and residues, especially when pollution reduction is not routinely addressed, with far-reaching effects on human health and the environment (Tian et al., 2015; Yang et al., 2024; Ma et al., 2025). In the **agriculture and food systems** sector, contamination can arise from residues and from bioaccumulation arising from unchecked use of pesticides and fertilizers, and irrigation with polluted water (Wang and Li, 2014; Mahfooz et al. 2020; Alengebawy et al., 2021; Naz et al., 2022; Rashid et al, 2023; Aslam et al., 2023; Su et al., 2025). The **buildings, construction, and infrastructure** sectors contribute where there are exposure risks from harmful substances in products, including from the generation of contaminated waste during construction, renovation, or demolition (Jacobs et al., 2013; Chen and Zhou, 2020; Molla et al., 2021; Manoharan et al., 2021; Molla et al., 2025).

Additionally, **consumer products**—including cosmetics, toys, cookware and electronics—can create exposure risks during manufacturing and use when harmful chemicals have been used in the products and precautions are not taken (Guney et al., 2012; Sousa et al., 2018; Turner and Filella, 2021). Finally, **waste management practices**, such as incineration and landfill, can release pollutants through emissions or leachate, particularly when hazardous waste is not properly segregated or treated (Huang et al., 2009; Bouida et al., 2022; Huang et al., 2024; Mathews et al., 2024; Nguyen et al., 2024; Wang and Qiao, 2024).

Several **policy options** have been considered to guide and coordinate action on pollution reduction:

- the establishment of a **unified global framework**, whether expanding the mandates of existing conventions, a new convention, or a protocol under an existing convention, ensure comprehensive governance;
- a **high-level political declaration** supported by a **global plan with targets**, which could mobilize political will;

- **voluntary market instruments**, such as eco-labeling programmes, and certification schemes, that give industry actors access to markets that reward reduction of pollution and exposure risks;
- **national regulations** to reduce pollution and exposure risks, with quick wins available from regulating the metal content or concentration in products that may result in high exposure risks, such as those with high human consumption (e.g. lead added to spices to enhance colour);
- **voluntary partnerships** to catalyze action, starting with those areas that are most policy relevant and practicable – similar to the lead in fuels initiative and lead in paint partnership, where countries learn from each other and take measures at their own pace.

Member States are invited to initiate discussions to determine the most effective framework for coordinated global action and a practical path forward. Member States are also encouraged to define a common policy objective and consider phased approaches that combine immediate voluntary measures with long-term binding commitments.

In considering immediate action, Member States are further encouraged to consider measures at regional, national, local and/or sectoral level that can effectively tackle the most pressing challenges posed by these substances across major sources, as well as the important legacy and new contamination paradigm – one that, if left unaddressed, will have lasting impacts on future generations.

Aligning efforts with the World Health Organization (WHO) Global Action Plan on Lead and other ongoing initiatives will be critical to ensure coherence and maximize impact. By leveraging existing mandates and scientific evidence, governments can protect populations from preventable exposure. **Reducing the environment and human exposure risks identified in this report can reduce public health costs and serve as an economic opportunity for government and businesses alike, if done correctly.**

Chapter 1. Introduction

1. This report is a direct response to the United Nations Environment Assembly resolution 6/9, which calls for a report "building on existing measures and initiatives to address lead, cadmium, arsenic and organotins." This report considers metals and metalloids in a broad sense, encompassing their elemental forms, as well as their inorganic and organic compounds. For example, organotins are the organic compounds of tins. These substances, commonly referred to as "heavy metals" or "toxic metals", belong to the group of well-known metals and metalloids[2] with a long history of international concern due to their adverse impacts on human health and the environment.

2. Among these substances, lead has received the most sustained global attention, and various international actions have been taken to reduce exposure from different sources. One of the earliest dates back to the adoption of the White Lead (Painting) Convention (C013)[3] by the International Labour Organization in 1921. Since then, and often in conjunction with cadmium, lead has been the subject of numerous resolutions by the Governing Council of the United Nations Environment Programme (UNEP), more recently the United Nations Environment Assembly (UNEA), and other international policy-making forums[4]. These resolutions have called for a broad spectrum of national and international measures to prevent and reduce exposure from various sources. Existing resolutions and international actions have primarily focused on lead in gasoline (e.g., under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade)[5], batteries (e.g., under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal)[6], paints (e.g., under the former Strategic Approaches to International Chemicals Management, SAICM)[7], and ammunition (e.g., under the Convention on the Conservation of Migratory Species of Wild Animals)[8], among other diverse sources of lead.

3. Cadmium is often addressed alongside lead and has also been cited in many international decisions and resolutions aimed at reducing exposure, including numerous UNEP Governing Council and UNEA resolutions[9].

4. Organotins, particularly tributyltin (TBT), have been partially addressed through international regulatory frameworks. Notably, the International Maritime Organization (IMO) adopted the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention)[10] in 2001, which prohibits the application or reapplication of organotin compounds acting as biocides in anti-fouling systems. Additionally, TBT compounds, a sub-set of organotins, have been listed under the Rotterdam Convention since 2017, subject to the prior informed consent (PIC) procedure.[11] However, other uses of organotins remain largely unregulated at the international level.

---

[2] This report considers metals and metalloids in a broad sense, encompassing their elemental forms, as well as their inorganic and organic compounds. For example, organotins are the organic compounds of tins.
[3] https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB:12100:0::NO::P12100_INSTRUMENT_ID:312158
[4] See Annex 1. A Non-Exhaustive Compilation of Major International Decisions and Resolutions Explicitly Referencing Lead, Cadmium, or Heavy Metals
[5] Under the Rotterdam Convention, two organolead compounds have been listed, subject to the prior informed consent (PIC) procedure: https://www.pic.int/TheConvention/Chemicals/AnnexIIIChemicals/tabid/1132/language/en-US/Default.aspx
[6] Under the Basel Convention, *Technical Guidelines for the Environmentally Sound Management of Waste Lead-acid Batteries* has been developed and published in 2003: https://www.basel.int/Portals/4/Basel%20Convention/docs/pub/techguid/tech-wasteacid.pdf
[7] Lead in paints had been identified as an emerging policy issue under SAICM: https://saicmknowledge.org/epi/lead-paint. At the first International Conference, scheduled for November 2026, a decision will be made on whether it will continue to be addressed under the Global Framework on Chemicals—For a Planet Free of Harm from Chemicals and Waste.
[8] https://www.cms.int/sites/default/files/document/cms_cop12_res.11.15%28rev.cop12%29_bird-poisoning_e.pdf
[9] See Annex I
[10]htps://www.imo.org/en/about/conventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx
[11] https://www.pic.int/TheConvention/Chemicals/AnnexIIIChemicals/tabid/1132/language/en-US/Default.aspx

5. Despite its well-documented acute toxicity, arsenic has received comparatively less international policy attention. Nevertheless, it is recognized by the World Health Organization (WHO) as one of the ten chemicals of major public health concern, alongside lead and cadmium.[12]

6. In 2019, UNEP's *Global Chemicals Outlook II: From Legacies to Innovative Solutions*[13] (GCO II) further identified these four substances as "issues where emerging evidence indicates a risk to human health and the environment".

7. Subsequently, UNEP developed the *Assessment Report on Issues of Concern: Chemicals and Waste Issues Posing Risks to Human Health and the Environment*[14] in 2020 (hereafter referred to as the "2020 Assessment Report"). The 2020 Assessment Report reviewed and synthesized scientific evidence on the key environmental fate and transport characteristics of these substances; their major sources of current exposure; and the prevalence, levels and trends of such exposure – reviewed in relation to existing instruments and actions addressing them. The report concludes that these issues have received limited attention, with actions showing uneven progress across countries and regions. Furthermore, where initiatives have been established and measures implemented, their scopes are not comprehensive; for instance, major sources of these substances are not comprehensively covered by existing initiatives and measures. The report highlights that, given the increasing global burden of disease, continued emissions, and several other considerations, these substances warrant urgent and concerted international action towards achieving the sound management of chemicals and waste as part of the 2030 Agenda.

8. UNEP launched the *Chemicals and Waste Issues of Concern: A Summary Analysis of Stakeholders' Views on Priorities for Further Work and Potential Further International Action*[15] in 2024, building on extensive consultations. Stakeholders supported the findings of the 2020 assessment report, emphasizing the serious health and environmental impacts of exposure to these substances and the urgent need for further action. Stakeholders stressed the importance of avoiding duplication, proposing the expansion or integration of efforts within existing instruments. Many stakeholders called for a legally binding instrument, similar to the Minamata Convention on Mercury, to address some or all of these substances. The value of partnerships was also highlighted, with suggestions for an initiative akin to the Global Mercury Partnership to support interim efforts. Also, the need for greater transparency regarding the uses and releases of these substances were emphasized.

9. In 2024 and 2025 – in collaboration with the United States Environmental Protection Agency, the European Union, and Japan's Ministry of Environment – UNEP conducted further consultations on lead in the Africa[16], Asia-Pacific[17] and Latin America and Caribbean[18] regions. The consultations emphasized the urgent need for preventative measures to reduce lead exposure, such as restricting the trade and import of lead-containing products and waste. The need for a comprehensive, multi-sectoral and coordinated approach involving all relevant government and societal actors was highlighted, along with the establishment of robust regulatory frameworks and effective enforcement. Participants recognized lead exposure as a transboundary issue and called for an internationally coordinated strategy, supported by regional platforms and international partnerships. They also stressed the importance of data-driven, context-specific solutions, noting that sources of lead exposure may vary across countries.

10. In response to UNEA resolution 6/9, this current analysis explores options for strengthening action on these substances to mitigate risks to human health and the environment, building upon UNEP's

[12] https://www.who.int/teams/environment-climate-change-and-health/chemical-safety-and-health/health-impacts/chemicals
[13] https://www.unep.org/resources/report/global-chemicals-outlook-ii-legacies-innovative-solutions
[14] https://www.unep.org/resources/report/assessment-report-issues-concern-chemicals-and-waste-issues-posing-risks-human
[15] https://www.unep.org/topics/chemicals-and-pollution-action/chemicals-management/issues-concern
[16] https://www.unep.org/events/webinar/towards-coordinated-multi-sectoral-lead-management-approach-low-and-middle-income
[17] https://www.unep.org/events/webinar/towards-coordinated-multi-sectoral-lead-management-approach-low-and-middle-income-0
[18] https://www.unep.org/events/online-event/towards-coordinated-multi-sectoral-lead-management-approach-latin-america-and

and others' previous work, existing initiatives and measures, and UNEP's *Study on options for global control of mercury* in 2007[19].

11. The analysis first provides a synthesis of key findings from previous assessments, along with more recent updates, which establish the rationale for enhanced action on these substances at all levels. It outlines major sources, uses and sectors relevant to these substances, highlighting the progress made and the limitations of current responses. Additionally, the report synthesizes critical characteristics of these substances that should be taken into account in the development of effective future policies.

12. Recognizing the need for stepwise approaches that account for economic, social and political contexts, the analysis then sets out examples of practical response measures that countries and other stakeholders can take in the short or medium term, reflecting sector-specific considerations and priorities. It also presents different policy options that can be taken, including both binding and non-binding instruments and measures that are international in scope, as well as other approaches that could be scaled through broader participation and coordination.

13. While illustrative examples are included to demonstrate how broader international options might function, this report does not provide an exhaustive inventory of existing national, regional or sectoral initiatives and measures.

14. The proposed options are meant to contribute to the achievement of the global commitments under the 2030 Agenda for Sustainable Development, particularly Goals 3, 6, 9, 12, 14 and 15, and respond to growing calls for integrated action on pollution as a driver of health inequities.

Chapter 2. Key findings from previous assessments

15. This chapter does not re-assess previously evaluated areas, but integrates key insights from previous work, particularly UNEP's 2020 Assessment Report (UNEP, 2020b), supplemented by more recent literature and developments where available. The goal is to provide a comprehensive, concise context – based on existing work – for compiling examples of practical response measures and the formulation and evaluation of the policy options presented in Chapter 3.

2.1 Urgent need for minimizing the risks of these toxic substances globally

16. Current evidence underscores the urgent need to reduce global risks from these substances, due to their high toxicity, persistence and widespread human and ecological exposure, among other concerning characteristics (UNEP, 2020b).[20] Notably, they are harmful to human health and the environment even at very low levels of exposure, including causing cancer, impairing neurodevelopment, disrupting endocrine systems and/or affecting immune responses, as shown by assessments from intergovernmental bodies, scientific literature (see Table 1) and many governments. Certain populations, such as women and children, are particularly susceptible to these substances and their adverse effects. Recent studies have found that lead, cadmium and arsenic, along with other heavy metals such as mercury, may contribute to the growing global health challenge of antimicrobial resistance (e.g., Gillieatt and Voleman, 2024; Balta et al., 2025).

17. Beyond toxicity, these substances exhibit additional hazardous traits that warrant further careful consideration. Lead, cadmium and arsenic are environmentally persistent, cycling through various chemical species but ultimately accumulating over time (UNEP, 2020b). Also, organotins may be persistent in certain environmental media, with degradation half-lives ranging from months to years,

[19] https://minamataconvention.org/sites/default/files/documents/working_document/OEWG1_2.pdf

[20] Lead, cadmium, arsenic, and organotins exist in various forms, both elemental and compound, in products and the environment, with varying physicochemical and toxic properties; however, these substances often transform between forms rather than remaining static (UNEP, 2020b). For simplicity, this report uses the element names to refer collectively to both their elemental and compound forms.

and even decades, in soil and sediment (UNEP, 2020b). This persistence results in potential long-term exposure and requires attention to the substantial quantities already released into the environment, even if emissions and releases could be immediately stopped. Additionally, cadmium bioaccumulates and has a biological half-life of a few decades in humans, mammals, and plants (Suwazono et al., 2009; Rasin et al., 2025). This means that even if exposure were entirely eliminated, absorbed cadmium would remain in the body and pose health risks for many years.

18. While most of these substances are non-volatile at ambient temperatures, methyltins are volatile and can thus travel long distances through the atmosphere over several days to weeks (UNEP, 2020b). Lead, cadmium and arsenic released at very high temperatures can be in a gas phase. From many anthropogenic unintentional sources – such as fossil fuel combustion and metal mining and smelting (see next section) – these metals can bind to fine particles, which facilitates their long-range atmospheric transport, spanning distances of up to several thousand kilometres (UNEP, 2020b). Such long-range transport is shown by measurements of aerosols and precipitation samples collected in remote regions, including Greenland, Tibetan Plateau, the Arctic Ocean and Antarctica (UNEP, 2010; Cullen and Maldonado, 2013; Bazzano et al., 2016; Liu et al., 2024). This pathway represents a significant vector of transboundary movement and warrants careful consideration (UNEP, 2020b). Zhang et al. (2020) estimate that approximately 3.55 billion and 4.09 billion people were living in environments with a carcinogenic risk from exposure to atmospheric arsenic from anthropogenic sources exceeding the threshold level (10^{-6}) globally in 2005 and 2015, respectively. Of these, an estimated 0.69 billion and 0.66 billion were children. The study further compares the carcinogenic risk from atmospheric arsenic exposure with that from groundwater at 32 sites. While in many sites the atmospheric risk is lower, certain locations exhibit higher levels of atmospheric arsenic exposure compared to groundwater, such as the Subarnarekha River in India, Khyber Pakhtunkhwa in Pakistan, and Dehgolan in Iran.

19. Exposure to these substances remains widespread, due to multiple pathways that connect various sources to human and environmental contact (UNEP, 2020b). Contaminated soils threaten food safety and agricultural productivity, with cadmium and arsenic levels exceeding thresholds in crop areas across Asia, Africa, and Latin America, thus damaging safe deliver of food security (Rosas Castor et al., 2014; FAO and ITPS, 2015; Rashid et al., 2023; Hou et al., 2025). For example, about 9% of global surface soil exceeds the agricultural thresholds for cadmium in crop areas – with notable concentrations in northern and central India, Pakistan, Bangladesh, southern China, southern parts of Thailand and Cambodia, Iran, Türkiye, Ethiopia, Nigeria, South Africa, Mexico and Cuba. Similarly, about 1% of global surface soil exceeds the agricultural thresholds for arsenic in crop areas, particularly in southern and southwestern China, South and Southeast Asia, West Africa, and central regions of South America. These exceedances are likely driven by both anthropogenic (e.g., mining and irrigation) and geogenic enrichment. Such contamination has significant implications for food production and safety, affecting hundreds of millions of people in high-risk areas (Hou et al., 2025). Also, the international trade of food products originating from these regions may contribute to the transboundary spread of associated risks (Nunes et al., 2022).

20. The widespread exposure contributes significantly to the global burden of disease, with rising trends over the past decade for lead, cadmium and arsenic. Partial estimates suggest over 1.5 million premature deaths and more than 34 million disability-adjusted life years (DALYs) loss in 2021, compared to nearly 0.7 million deaths and 14 million DALYs in 2010 (see Table 1). It is further estimated that the global human health cost associated with IQ loss and cardiovascular disease mortality from lead exposure alone amounted to US$6 trillion in 2019. These figures reflect widespread, extensive exposure among children, leading to irreversible neurodevelopmental damage, and ongoing health burdens in affected populations. Notably, the burden is disproportionately concentrated in low- and middle-income countries – for example, 95.3% of global IQ loss in children under five due to lead exposure occurs in these countries – thereby contributing to persistent global health disparities (Larsen and Sánchez-Triana, 2023). While no global disease burden has been identified for organotins, regulation of tributyltin in the EU is estimated to have annual benefits of EUR 22-158 million for commercial fishing, whereas the

absence of regulation could have resulted in EUR 21-237 million in remediation costs (Amec Foster Wheeler and EC, 2017).

21. The figures above represent only a portion of the broader impact that can be estimated. For cadmium and arsenic, assessments have focused solely on the global burden of disease related to occupational and foodborne exposure, while other pathways such as consumer exposure remain unquantified (see Table 1). In addition, society bears a range of other costs – including those related to medical treatment, environmental remediation, property devaluation, ecosystem and biodiversity loss, and social equity concerns – for which current understanding remains limited (Ateia et al., 2023).

Table 1. A non-exhaustive overview of the environmental and human health concerns of lead, cadmium, arsenic and organotins. This includes examples of assessment outcomes by intergovernmental institutions, global burden of disease estimates, and other key hazardous traits reported in UNEP's 2020 Assessment Report, updated with recent information where available. DALYs = disability-adjusted life year; IARC = International Agency for Research on Cancer; N.A. = not available.

	Lead	**Cadmium**	**Arsenic**	**Organotins**
Examples of environmental and human health effects based on assessments by inter-governmental institutions[21]	- Exposure poses serious health risks to people of all ages, especially infants and children, with no safe threshold for its harmful effects on cognitive development (UNEP, 2020b). - *IARC (2006)*: inorganic compounds as probably carcinogenic to humans (Group 2A); organic ones as not classifiable as to their carcinogenicity to humans (Group 3). - Millions of waterbirds are poisoned by lead shot or sinkers (UNEP, 2010a). - Listed by WHO as Chemicals of Major Public Health Concern. - WHO provisional[22] guideline value of 10 µg/L lead in drinking water.	- Cadmium and cadmium compounds as carcinogenic to humans (Group 1) with sufficient evidence in humans for causing lung cancers and positive associations observed between exposure and cancer of the kidney and of the prostate *IARC (1993)*. - Exposure causes kidney damage in animals and is toxic to plants and microorganisms (UNEP, 2010b). - Listed by WHO as Chemicals of Major Public Health Concern. - WHO guideline value of 3 µg/L cadmium in drinking water.	- Arsenic and inorganic arsenic compounds as carcinogenic to humans (Group 1), dimethylarsinic and monomethylarsonic acids as possibly carcinogenic to humans (Group 2B), arsenobetaine and other organic arsenic compounds that humans do not metabolise are not classifiable as to their carcinogenicity to humans (Group 3) *IARC (2012)*. - Arsenic-contaminated environments are characterized by limited species abundance and diversity (WHO, 2001). - Listed by WHO as Chemicals of Major Public Health Concern. - WHO provisional guideline value of 10 µg/L arsenic in drinking water.	- Methyltins and ethyltins are highly neurotoxic; dibutyltin (DBT), tributyltin (TB)), monooctyltin and dioctyltin (DOT) are highly immunotoxic (WHO, 2006). - In aquatic environments, TBT compounds can cause male traits in female marine snails and may trigger sex reversal in fish (WHO, 1999). - WHO health-based value of 1.5 µg/L for the sum of TBT, TPT, DBT and DOT in drinking water.
Global burden of disease estimates in 2021 (vs. 2010) [23]	1.54 million (vs. 674,000) premature deaths, 33.9 million (13.9 million) DALYs.	*Solely occupational exposure:* 809 (vs. 555) premature deaths, 23,500 (vs. 13,000) DALYs.	*Solely occupational exposure:* 10,500 (vs. 2,600) premature deaths, 299,000 (vs. 63,000) DALYs .	N.A.
Other global burden of disease estimates	In 2015, global lead exposure was linked to: - 12.4% of idiopathic intellectual disability, 2.5% of ischaemic heart disease, and 2.4%	Foodborne cadmium is estimated to account for about 12,000 new severe and end-stage chronic kidney disease cases, 2,000 deaths and 70,513 DALYs	Inorganic arsenic in food is estimated to cause: - 9,129–119,176 bladder, 11,844–121,442 lung, and 10,729–110,015 skin cancer cases each year (Oberoi et al., 2014);	N.A.

[21] All IARC monographs on the identification of carcinogenic hazards to humans can be found at https://monographs.iarc.who.int/monographs-available/; more information on WHO's 10 chemicals of public health concern can be found at https://www.who.int/news-room/photo-story/detail/10-chemicals-of-public-health-concern; the latest WHO *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda* can be found at: https://www.who.int/publications/i/item/9789240045064.
[22] The guideline value is designated as provisional on the basis of treatment performance and analytical achievability.
[23] Lancet Global Burden of Disease (GBD) Resource Centre: https://www.thelancet.com/gbd (last update: May 2024)

	of stroke cases (IHME, 2016); - 5.23 million DALYs (foodborne lead; Gibb et al., 2019).	worldwide in 2015 (Gibb et al., 2019).	- 1.4 million DALYs for related cancers each year (Gibb et al., 2019).	
Other key hazardous traits based on UNEP's 2020 Assessment Report	- Persistence in the environment.	- Persistence in the environment. - Bioaccumulation, including in plants, crayfish, wildlife, and humans (with a biological half-life of 10–35 years).	Persistence in the environment, cycling between inorganic and organic forms.	- Methyltins are volatile, with some lasting days to weeks in the atmosphere (Krupp et al. 2011).

2.2 Diverse yet similar source profiles, predominantly from human activities

22. The major sources of these substances in both environmental and human exposure are diverse and varied, encompassing natural origins as well as those resulting from human activities (see Table 2). Anthropogenic sources can be further divided into unintentional and intentional ones. Unintentional sources typically arise from activities involving materials that contain trace amounts of these substances, where the objective is unrelated to the production, use or disposal of the substances themselves (e.g., combustion of fossil fuels). Intentional sources pertain to the deliberate production, utilization and disposal of these substances and related products.

23. Numerous studies have shown that human activities significantly contribute to global exposure to these substances, underscoring the prominent role of anthropogenic sources (UNEP, 2020b).

    a. *Lead.* It is estimated that in the mid-1990s, anthropogenic lead emissions to the atmosphere reached approximately 120,000 tonnes annually – ten times higher than the median natural flux of 12,000 tonnes (Cullen and McAlister, 2017). Similarly, natural riverine lead inputs to the ocean were estimated at around 295,000 tonnes per year, accounting for only about one-third of the total annual oceanic lead flux of 950,000 tonnes (Viers et al., 2009). Records from remote lakes, peat mires and ice fields worldwide reveal current global lead enrichment rates ranging from 6 to 35 times natural background levels, with notable regional variation – exceeding 100 times in Europe and North America, and 5 to 15 times in Antarctica (Marx et al., 2016). These findings align with evidence of anthropogenic lead dominance in a 2,000-year ice core from a Swiss alpine glacier (More et al., 2017, 2018) and in surface waters across the global ocean (Bridgestock et al., 2016; Pinedo-Gonzalez et al., 2018; Rusiecka et al., 2018; Gamo, 2020).

    b. *Cadmium.* Anthropogenic activities release substantial quantity of cadmium, contributing to air pollution, especially in urban areas where cadmium concentrations range from 2 to 15 ng/m^3 (Rasin et al., 2025). On instances, such as in Mexico City, cadmium levels in fine particulate matter (PM2.5) have been reported to be as high as 35 to 40 ng per cubic meter (Lee et al., 2020; Singh et al., 2021). Anthropogenic emissions to the atmosphere were estimated at approximately 7,600 tonnes in 1983, 2,400 tonnes in 1991 and 3,000 tonnes by the mid-1990s, primarily originated from fossil fuel combustion, mining and metal smelting (Nriagu and Pacyna, 1988; Jackson and Macgillivray, 1995; Pacyna and Pacyna, 2001). In contrast, natural atmospheric sources contributed an estimated 150 to 2,600 tonnes annually, with over 60% from volcanic activity and around 15% from windblown dust (Nriagu, 1989). Cadmium emissions to water and solid waste from anthropogenic sources were estimated at 1,200-13,400 tonnes and 9,900-45,000 tonnes, respectively, in 1983, and 1,100 and 23,810 tonnes in 1991. These were largely linked to the production, use, disposal and recycling of cadmium-containing products, with smaller contributions from fossil fuel combustion and metal processing activities (Nriagu and Pacyna, 1988; Jackson and Macgillivray, 1995).

c. *Arsenic*. Anthropogenic atmospheric emissions of arsenic were estimated at 12,000-28,000 tonnes per year in the 80s, accounting for approximately 66% to nearly 90% of total atmospheric emissions (Chilvers and Peterson, 1987; Nriagu and Pacyna, 1988; Matschullat, 2000; WHO, 2000, 2001; Wai et al., 2016). Annual anthropogenic releases to soil and water were estimated at 24,000-132,000 tonnes and 12,000-70,000 tonnes, respectively (Nriagu and Pacyna, 1988; Matschullat, 2000). By 2000, cumulative global emissions from fossil fuel and coal combustion reached about 1.24 million tonnes, while mining and smelting activities contributed around 3.3 million tonnes – some directly released during processing, and the rest through product use and disposal (Han et al., 2003). Copper smelting and coal combustion alone accounted for about 60% of anthropogenic atmospheric arsenic emissions, with the remainder linked to intentional production and use (Matschullat, 2000). In the recent literature, natural sources such as volcanic eruptions and soil erosion, contribute approximately 2,100 tonnes/year; however, anthropogenic activities, notably metal smelting and coal combustion, dominate emissions, with global anthropogenic releases reaching approximately 28,600 tonnes/year. Atmospheric arsenic primarily exists in two forms: particulate matter ($PM_{2.5}$-bound As(V)/As(III) and methylated species) and gaseous forms (e.g., AsH_3, As_2O_3), facilitating long-range transport and cross-continental pollution, as evidenced by Asian emissions contributing 39% of Arctic deposition (Liu, 2025).

d. *Organotins*. With the exception of certain methylated compounds produced by microbial activity, these substances are primarily of anthropogenic origin (Sousa et al., 2014). For instance, a study of marine organisms from the seas adjacent to eastern Chinese ports suggests that certain organotin compounds primarily originate from historical use of antifouling coatings on ships, while others may be closely linked to coastal aquaculture and terrestrial agriculture-related activities (Shu et al., 2023). Organotins may be released during production; through use, such as direct releases from pesticides, and leaching from ship hulls and PVC piping; and disposal, such as from landfills, through the removal of old organotin paint from ships during maintenance, and through leaching from PVC microplastics (Fent, 1996a,b; Rantakokko et al. 2006; Guerin et al., 2007; Santos et al., 2009; Airaksinen et al., 2010; Choi et al., 2012; Krupp et al., 2010; Yi et al., 2012; Sousa et al., 2014). Also, evidence shows that organotin stabilisers used in PVC do not only pose occupational exposure risks during manufacturing (Boraiko et Batt, 2005; RPA 2005; UNEP, 2020b; Cläsgens et al. 2024); they may also leach from PVC pipes into drinking water systems (Quevauviller et al. 1991; Sadiki et al., 1996; Sadiki and Williams 1999; Forsyth and Jay, 1997; Jones-Lepp et al., 2001; Fristachi et al. 2009; Adams et al., 2011; Chen et al. 2022) and may be released from PVC microparticles under environmental conditions (Peeters et al. 2014; Chen et al. 2019)

24. While recent emission estimates are limited, it is likely that emissions have increased, at least in certain regions, driven by rising production and consumption volumes and reflected in the growing global burden of disease (see Paragraphs 15 and 16, and Table 1; UNEP, 2020b). For example, global demand for refined lead (primary and secondary) rose from 6.2 million tonnes in 1999 to 13.1 million tonnes in 2024 (USGS, 2025a); global refined cadmium production increased from 19,900 tonnes in 1999 to 24,000 tonnes in 2024 (USGS, 2025b); and global arsenic trioxide production grew from 38,800 tonnes in 1999 to 58,000 tonnes in 2024 (USGS, 2025c). Limited data are available on global organotin production and use, particularly over the past decade. Early estimates suggested annual production was around 60,000 tonnes in the early 2000s, with approximately 76% used in the PVC industry and less than 20% as biocides and pesticides (Nath, 2008; Sousa et al., 2014). By 2015, China accounted for about 40% of global organotin consumption, with 93% used as heat stabilizers in PVC manufacturing – exceeding 60,000 tonnes (IHSMarkit, 2016). Organotin stabilizers are critical additives used primarily in polyvinyl chloride (PVC) processing to prevent thermal degradation. These organometallic compounds enhance PVC's heat stability during manufacturing while maintaining transparency – a key requirement for applications like packaging and building materials (24 Chemical Research, 2025). The demand for PVC is projected to increase along with the world's population and economies, setting the material's production and use to new heights (Alsabri and Al-Ghamdi, 2020; Hughes, 2021;

Sawlani, 2023; Seewoo et al., 2024; Verified Market Research, 2024). PVC products for the building sector are key materials driving the growth of the PVC significance and its market worldwide (Masseck et al., 2024; Seewoo et al., 2024; Verified Market Research, 2024).

25. Production of lead, cadmium and arsenic occurs through distinct pathways, including both primary extraction and secondary recycling (USGS, 2025a,b,c), with key implications for their sound management. Lead is produced through both direct mining from dedicated lead deposits and as a by-product of zinc and silver extraction (USGS, 2025a). Cadmium is primarily recovered as a by-product of processing zinc concentrates (USGS, 2025b), and arsenic is mainly obtained in the form of arsenic trioxide during the smelting or roasting of nonferrous metal ores (USGS, 2025c) such as copper and gold (Nriagu, 1989; Pacyna et al., 2009; Gibb et al., 2009). These substances are intentionally used in a wide range of applications across multiple sectors (see Table 2, noting that the actual range of economic sectors is broader than presented, as some uses involve materials such as PVC that may serve as inputs for products or processes in many other sectors). These substances may be released throughout their life cycle, including during production, use, recycling and end-of-life disposal – particularly in cases of improper waste management (UNEP, 2020b). For example, informal recycling of lead-acid batteries in low-income countries remains a major source of lead exposure for millions (Gibb et al., 2019).

26. In addition to their unintentional anthropogenic sources, many uses of these substances overlap within the same sectors – for example, lead in lead-acid batteries and cadmium in nickel-cadmium batteries; arsenic and organotins in pesticides and wood preservatives; and lead, cadmium and organotins as stabilizers in PVC production. Notably, many sources of these substances share characteristics with those of mercury, including both unintentional anthropogenic emissions such as fossil combustion and certain intentional uses, such as in batteries (see Table 2).

27. The diversity and commonalities of major sources highlights the need for a comprehensive set of measures tailored to specific applications/sectors, while also offering opportunities for synergistic approaches that address multiple elements within similar applications/sectors – including that existing experience in managing certain metals may provide valuable insights for addressing others (UNEP, 2020b). For example, existing efforts to manage mercury emissions from certain sources may yield co-benefits in reducing lead, cadmium and arsenic releases, as elaborated below, while also enabling cross-element learning to strengthen overall practices. Such multi-pollutant control strategies not only enhance cost-efficiency by delivering co-benefits but also help to avoid long-term challenges such as regrettable substitution: for example, lead replaced cadmium as a heat stabilizer in PVCs, only to be later replaced by organotins (UNEP, 2020b; Wiesinger et al., 2024).

Table 2. Overview of the major sources of lead, cadmium, arsenic and organotins to the environment, using mercury as a reference for comparison. This overview is not exhaustive. Some uses may span multiple sectors (e.g., lead, cadmium and arsenic-containing pigments may be used in different materials); therefore, the sector categorization presented here is indicative rather than definitive. Sources: UNEP (2018, 2020); USGS (2025a,b,c)

Source/sector	Lead	Cadmium	Arsenic	Organotins	Mercury (used as a reference)
Natural sources					
Volcanic activity; vegetation exudates; windblown dusts; biomass burning and wildfires; permafrost thawing	Yes	Yes	Yes	No	Yes
Anthropogenic sources, unintentional					
Fossil fuel combustion (e.g., cement production, coal power plant)	Yes	Yes	Yes	No	Yes
Mining, and metal smelting and roasting	Yes	Yes	Yes	No	Yes
Waste incineration	Yes	Yes	Yes	Yes	Yes

Contaminants in phosphate fertilizer	Yes	Yes	Yes	No	No
Anthropogenic sources, intentional production, use, disposal and recycling					
Agri-food			Pesticides; animal feed additives	Pesticides; dewormers in poultry farming	
Buildings, construction and infrastructure	Lead pipe, sheets, roofing materials, paints; via PVC	Via PVC; galvanized steel products; paints	Wood preservatives	Wood preservatives; via PVC	
Chemicals and pharmaceuticals			Pharmaceuticals	Contaminants and intermediates	Chlor-alkali production
Cosmetics and personal care products	Yes (e.g., lead acetate in hair dye)	Yes	Yes	Yes	Yes
Electronics	Cable sheathing and soldering	Semiconductor manufacturing; quantum dot displays; etc.	Electronics and semiconductor manufacturing		Electrical and electronic devices
Energy	Lead-acid batteries; solar panels	Solar cells; nickel-cadmium batteries			Batteries
Glass	Lead glass	Pigments	Glass production	For depositing tin oxide coatings on reuseable glass bottles and other glass products	
Mining and metals (used in multiple other sectors, such as textiles and toys)	Alloys	Alloys; coatings; plating	Alloy manufacturing		Artisanal and small-scale gold mining
Plastics (used in multiple other sectors, such as toys)	PVC stabilisers	PVC stabilisers; pigments		PVC stabilisers; catalysts in production of polyurethan foams and silicones	Vinyl chlorine monomer production
Textiles (can contain parts from multiple sectors)	Pigments and dyes	Pigments and dyes	Pigments and dyes	Biocides	
Transport	Additives in fuels			Antifouling systems for ships	
Others	Ammunition; pigments; rolled and extruded products (e.g., lead sheets); spices; cookware; religious items; others	Pigments in ceramics and paints; others			Measuring devices; dental applications; cosmetics; biocides and topic antiseptics; lamps

2.3 Many measures and initiatives exist, but they are not sufficient to address the full range of sources and exposures

28. Numerous efforts have been undertaken at international, regional, national and sectoral levels to address these four substances. These include a broad range of legally binding instruments, non-binding arrangements,[24] and voluntary measures and initiatives led by governments and other stakeholders. While many initiatives and measures have made significant progress in addressing specific aspects of these substances (e.g., phasing out lead in gasoline), current efforts remain fragmented and do not yet comprehensively address the full scope of global exposure (UNEP, 2020b). Therefore, without a coordinated and adequately financed global approach, the current

[24] They refer to non-legally binding tools such as agreements, principles, declarations, resolutions, codes of conduct, guidelines, strategies, action plans, and fiscal policies. While not enforceable by law, these instruments establish norms and expectations set by governments or intergovernmental organizations.

array of measures will leave large and growing populations unprotected, perpetuating preventable harm and economic losses.

29. For unintentional sources such as fossil fuel combustion and metal smelting, a key international instrument is the 1998 Aarhus Protocol on Heavy Metals under the 1979 Convention on Long-Range Transboundary Air Pollution (CLRTAP).[25] This protocol targets lead and cadmium, along with mercury, aiming to reduce emissions from industrial activities, combustion processes and waste incineration. It establishes stringent emission limit values for stationary sources and recommends best available technologies (BATs), such as specialized filters and scrubbers for combustion sources. However, its geographic coverage is limited to the European Union (EU) and 35 countries in Europe and North America. Another relevant instrument is the Protocol on Pollutant Release and Transfer Registers (PRTR Protocol) under the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, [26] which includes these substances, alongside mercury. Its objective is to enhance public access to pollution data through the establishment of coherent, nationwide PRTRs, which are expected to exert downward pressure on pollution levels.[27] Despite its potential, the protocol's practical effectiveness in reducing emissions and releases remains uncertain when considered in isolation, as additional steps beyond PRTRs are necessary to translate reported values into concrete measures (Kerret and Gray, 2007). Also, its geographic scope is limited. Although open to all UN Member States – not limited to parties to the Aarhus Convention or members of the UN Economic Commission for Europe – only the EU and 37 countries had ratified the protocol as of 1 April 2025.

30. A wide range of measures and initiatives exist to address the intentional production, use and disposal of these substances and related products. At the international level, a number of legally binding or non-binding instruments and initiatives on these substances have been established. While these instruments represent important progress, they typically address specific substances, applications, activities (e.g., trade), and/or life cycle stage(s) (e.g., waste). They do not constitute a comprehensive framework for managing the full scope of these substances (UNEP, 2020b).

    a. Global legally binding instruments include:

        i. The ILO C013 White Lead (Painting) Convention[28], which addresses a specific use of lead;
        ii. The Rotterdam Convention [29] lists tetraethyl and tetramethyl lead compounds (in the industrial category) and tributyltin compounds (in both the pesticide and industrial categories) in Annex III, thus making them subject to the Prior Informed Consent (PIC) procedure – addressing a subset of lead and organotins within a specific type of activity;
        iii. The Basel Convention[30] classifies wastes consisting, containing or contaminated with lead, cadmium and arsenic as hazardous wastes, and may cover waste organotin compounds in waste streams to be controlled[31] as well as waste presumed to be hazardous[32] listed in Annex VIII – addressing these substances within a specific stage of their life cycle; and
        iv. The AFS Convention[33], which restricts the use of organotins as biocides in ship coatings – addressing one use of organotins.

---

[25] https://eur-lex.europa.eu/EN/legal-content/summary/geneva-convention-on-long-range-transboundary-air-pollution.html
[26] https://unece.org/fileadmin/DAM/PRTR_Protocol_e.pdf
[27] https://unece.org/fileadmin/DAM/PRTR_Protocol_e.pdf
[28] https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB:12100:0::NO::P12100_INSTRUMENT_ID:312158; it has ratifications from 63 countries, as of 22 October 2025.
[29] https://www.pic.int/TheConvention/Chemicals/AnnexIIIChemicals/tabid/1132/language/en-US/Default.aspx; it has 167 Parties, consisting of the European Union and 166 countries, as of 22 October 2025.
[30] https://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx; it has 191 Parties, consisting of the European Union and 190 countries, as of 22 October 2025.
[31] Such as "Wastes from the production, formulation and use of biocides and phytopharmaceuticals (Y4)" or, "Wastes from the manufacture, formulation and use of wood preserving chemicals (Y5)."
[32] Such as "Wastes arising from the production of aliphatic halogenated hydrocarbons (such as chloromethane, dichloro-ethane, vinylchloride, vinylidene chloride, allyl chloride and epichlorhydrin) (A3170)"
[33] https://www.imo.org/en/about/conventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx; it is ratified by 102 countries and local governments, as of 22 October 2025.

b. Global non-binding /soft law initiatives include:

i. Resolution 11.15[34] on preventing poisoning of migratory birds, adopted by the Convention on the Conservation of Migratory Species of Wild Animals, highlights the need for practical guidance on reducing lead exposure from hunting and fishing. This led to the development of *Guidelines to Prevent the Risk of Poisoning to Migratory Birds*,[35] recommending the phase-out of lead ammunition across all habitats, promotion of non-toxic alternatives, leadership from ammunition users, and remediation of lead-contaminated sites – addressing a specific use of lead (though it also includes the remediation of contaminated sites).

ii. The Basel Convention has adopted several technical guidelines[36] on the treatment of specific waste streams related to these substances, such as the *Technical Guidelines for the Environmentally Sound Management of Waste Lead-acid Batteries* (currently being updated), the *Technical Guidelines on the Environmentally Sound Recycling/Reclamation of Metals and Metal Compounds (R4)*, and the *Technical Guidelines on the Environmentally Sound Management of Plastic Waste* – addressing these substances within a specific stage of their life cycle.

iii. WHO and the Food and Agriculture Organization of the United Nations (FAO) have developed a number of international guideline values for the presence of these substances in drinking water, air, and/or food items[37] – addressing these substances within a specific stage of their life cycle.

iv. International forums, including meetings of the governing bodies of UNEP and WHO, as well as the United Nations Conference on Environment and Development, have adopted a number of resolutions over the past couple of decades (see Annex 1). In addition to broadly recognizing the risks posed by lead and cadmium at the international level, these resolutions have largely placed the responsibility for implementation on individual governments and other stakeholders. They call upon these actors to take action to reduce risks to human health and the environment throughout the entire life cycle of these substances, often with explicit references to the use of lead in gasoline and paints, as well as the environmentally sound management of waste lead-acid batteries. At the same time, they have repeatedly encouraged international cooperation to support national efforts, including through information exchange, technical assistance, capacity-building, financial support and other relevant measures. Most recently, Resolution WHA78.27, adopted by the World Health Assembly (WHA) in 2025, introduced the concept of a shared vision for a world free from lead exposure and called for the development of a WHO global action plan on lead mitigation (see Annex 1). The implementation of this resolution warrants further attention.

31. At the regional, national and sectoral levels, a diverse array of measures and initiatives has been implemented to address these substances, of both legally and non-legally binding natures (for examples, see the Annexes of UNEP's 2020 Assessment Report[38]). Legally binding instruments – such as bans or restrictions (including the setting of threshold values in products), market authorizations, mandatory national standards for specific applications, and export notifications for certain substances – play a significant role. In parallel, non-binding measures – including risk management strategies, codes of practice, priority lists for control and recommended national standards – have also been developed and applied. Voluntary approaches are widely adopted by a broad range of stakeholders, including individual companies and industry associations within specific economic sectors. These include the development of guidance and tools, voluntary phase-outs and stewardship programmes, third-party standards and certification schemes, and monitoring activities. However, the scope and coverage of these measures vary considerably across regions and

[34] https://www.cms.int/sites/default/files/document/cms_cop14_res.11.15_rev.cop14_preventing-poisoning-of-migratory-birds_e_0.pdf
[35] https://raptors.cms.int/sites/default/files/document/Guidelines%20to%20prevent%20the%20risk%20of%20poisoning%20to%20migratory%20birds.pdf
[36] https://www.basel.int/implementation/technicalmatters/developmentoftechnicalguidelines/technicalguidelines/tabid/8025
[37] In the form of tolerable weekly intake
[38] https://wedocs.unep.org/bitstream/handle/20.500.11822/33809/IOCA.pdf

economic sectors. While targeted actions have been implemented for specific substances in certain applications and regions, these measures and initiatives collectively still cannot cover the full extent of exposure to these substances around the world. For example, some regions have implemented broad and systematic restrictions, whereas other regions have adopted narrower or less consistent controls. As of 16 January 2024, 48% of countries have confirmed that they have legally binding controls on the production, import, sale and use of lead paints.[39]

32. One notable exception to the otherwise fragmented global response is the earlier coordinated effort that successfully led to the phase-out of lead in gasoline. This success was driven by several international instruments and actions, including early political commitment such as the UN Commission on Sustainable Development's call for governments to eliminate leaded petrol. Additional support came from initiatives led by the World Bank, UNECE, OECD, the United States, Canada, and others, which assisted developing countries through baseline assessments, phase-out strategy development, technical assistance and financing (OECD, 1996; Lovei, 1999; The LEAD Group, 2011). The establishment and operation of the public-private Partnership for Clean Fuels and Vehicles (PCFV) by UNEP (Todd and Todd, 2010), along with the listing of key lead additives – tetraethyllead (TEL) and tetramethyllead (TML) – in Annex III of the Rotterdam Convention in 2004 (Rotterdam Convention, 2005), further contributed to this global effort. At the same time, despite the major achievements of phasing out lead in fuel for vehicles globally, lower amounts of lead continue to be used in other fuels, including those for aircraft, agricultural machinery and high-performance competition vehicles (Kessler et al., 2013). Notably, several thousand tonnes of lead were still traded globally as recently as 2019 (Zou et al., 2023).

33. In addition to the aforementioned measures targeting diverse sources, legally binding, non-binding or voluntary guidelines have also been established at different levels to set exposure limits across various media, including occupational settings, drinking water, air, food and other environmental compartments (see the Annexes of UNEP's 2020 Assessment Report). While these limits are critical and bringing significant health benefits – particularly in controlling human exposure – they are largely end-of-pipe solutions and should be regarded as a secondary line of defense, with priority given to reducing pollution at its source. This is because remediation of contaminated exposure media often occurs only after large-scale exposure has already taken place (e.g., the case of large-scale lead exposure via drinking water in Flint, U.S.; Masten et al., 2017). Such remediation is highly complex, costly[40] and, in many cases, only marginally effective or not feasible at all.

34. Although existing actions to address these substances remain fragmented, the implementation of phase-out measures in specific uses is advancing in some parts of the world. This progress also reflects the availability of many technically feasible and economically viable substitutes. As shown by the examples below,[41] these range from chemical and non-chemical alternatives to innovative product designs that eliminate the need for these substances. This highlights the potential for a broader transition away from their use, including the possibility of cross-application transfers, where appropriate and subject to specific application requirements. It is also vital to properly assess alternatives from both environmental and human health perspectives prior to large-scale deployment, in order to avoid replacing one environmental issue with another – commonly referred to as regrettable substitution. A notable example is the use of organotins to replace lead, which had previously replaced cadmium, as heat stabilizers in PVC (UNEP, 2020b; Wiesinger et al., 2024). It is key to acknowledge that suitable replacements are not yet available for all applications of these substances. In such cases, other risk management measures, along with continued support for innovation, particularly application-specific research and development, remain essential.

    a. **Examples for lead** (UNEP, 2022a; USGS, 2025a): The electronics industry has transitioned toward lead-free solders and flat-panel displays that no longer require lead shielding. Plastics

[39] https://www.who.int/data/gho/data/themes/topics/indicator-groups/legally-binding-controls-on-lead-paint
[40] https://www.houselogic.com/remodel/painting-lighting/lead-paint-removal/
[41] For the examples provided here, their environmental and human health performance has not been assessed by this report. They are included solely to illustrate the availability of alternatives and should not be interpreted as endorsements of these options as the most suitable substitutes.

may replace lead in cable coverings and cans, while tin is now commonly used in solder for potable water systems. In automotive applications, steel or zinc are widely used as substitutes for lead in wheel weights. Various alternatives have been developed to replace lead in paints.

b. **Examples for cadmium** (USGS, 2025b): Lithium-ion and other battery chemistries have largely replaced nickel-cadmium (NiCd) batteries. In plating, zinc-nickel coatings are used as substitutes, except where specific surface characteristics are critical, such as in aircraft fasteners. Cerium sulfide has replaced cadmium pigments, particularly in plastics, and barium stabilizers are used instead of barium-cadmium stabilizers in flexible PVC.

c. **Examples for arsenic** (USGS, 2025c): Alternatives to chromated copper arsenate (CCA) in wood preservation include using non-wood materials such as concrete, plastic composites and steel to replace wood, or chemical replacements to CCA such as alkaline copper quaternary, ammoniacal copper zinc arsenate, copper azole, copper citrate and copper naphthenate.

2.4 Internationally coordinated, life cycle-based and sectoral-specific approaches are needed to address these substances

35. As highlighted in the key findings outlined above, minimizing the global risks posed by these substances requires urgent action through enhanced measures and initiatives. This urgency is underscored by the increasing long-term burden on human health and the environment, as well as the associated societal costs. While existing measures and initiatives remain insufficient to fully address the challenge, they provide a valuable foundation and offer important insights that should inform the development of future actions.

36. It is necessary to protect human health and the environment from all anthropogenic emissions and releases of these substances using a life-cycle approach that covers supply, trade, use, emissions, releases (including unintentional ones), storage, waste management and contaminated sites, as exposure and risks may occur across their entire lifespan. Importantly, it is key to cover both supply and demand, as lead, cadmium and arsenic are generated as by-products of mining activities. Targeting demand reduction in a single application is unlikely to address the broader supply issue, as these substances may be redirected to alternative uses to offset decreased demand. Additionally, a decline in demand in one region will likely be counterbalanced by increased consumption elsewhere, particularly in jurisdictions with less stringent regulatory frameworks (see the cases of asbestos and paraquat in Blumenthal et al., 2022). These dynamics highlight the importance of globally coordinated strategies that reflect the complex interdependencies within supply chains and market systems.

37. It is also essential to recognize both the diverse and shared characteristics of different economic sectors in relation to the emissions and releases of these substances, including their presence in consumer products. Sources, such as fossil fuel combustion and metal smelting, can emit fine particles containing lead, cadmium and arsenic. These emissions are generally distinguishable from those arising from intentional production and use at lower temperatures, while they may share similarities with emissions from incineration of product waste containing these substances. Similarly, sectors intentionally using these substances in their production process (e.g., use of cadmium as catalyst for certain chemical reactions) face a distinct set of challenges and opportunities compared to consumer-facing sectors (such as the use of cadmium as a pigment in plastics). Additionally, the end-of-life stage presents distinct challenges, particularly in informal e-waste recycling and lead-acid battery dismantling. These activities require targeted efforts to promote environmentally sound disposal practices, especially among informal actors – whose operations differ significantly from those of formal actors in other economic sectors. Given these differences, it is important to develop sector-specific strategies that address the unique patterns of use, emission, releases, exposure and operational contexts associated with individual sectors. It is equally important to identify commonalities across these substances within particular sources or sectors, as these can offer valuable opportunities for integrated and synergistic mitigation approaches. For example, the UNECE *Guidance Document on Best Available Techniques for*

Controlling Emissions of Heavy Metals and Their Compounds from the Source Categories Listed in Annex II[42] notes that the same techniques can simultaneously remove lead, cadmium and mercury from different industrial sources. This is also emphasized in Articles 8 and 9 of the Minamata Convention, which call for "a multi-pollutant control strategy that would deliver co-benefits for control of mercury emissions/releases". As such, there could be grouping of the sectors, similar to what is done under the Minamata Convention: (1) mining and other supply sources; (2) trade; (3) products that these substances are added to; (4) industrial processes using these substances; (5) unintentional emissions and releases; and (6) any special uses requiring separate attention.

38. Finally, it is critical to ensure international cooperation and globally coordinated approaches across sectors and regions in a comprehensive life-cycle approach reflecting the globalized nature of production, trade and impacts on human health and the environment – in addition to the ubiquitous presence and challenges of these substances around the world. Addressing the challenges posed by these substances requires not only sector-specific strategies but cross-border collaboration to ensure effective and equitable outcomes, as illustrated below:

    a. *Long-range atmospheric transport:* For example, emissions of lead, cadmium and arsenic from anthropogenic unintentional sources, such as fossil fuel combustion and metal smelting, are often as fine particles. Due to their small size, these pollutants can travel thousands of kilometres from their original sources, contributing to transboundary pollution. Additionally, some organotins are volatile and can thus travel long distances through the atmosphere over days or weeks.

    b. *Global trade and waste flows:* Emissions and releases from lower-temperature processes, such as those associated with the production and use of these elements in consumer products, are often considered to have primarily local or regional impacts. However, the global trade of products and waste complicates this picture. For instance, end-of-life products in some regions may be subject to open burning or substandard waste incineration, leading to the emission of fine particles capable of long-range transport. Landfilling of products containing these substances, in the absence of proper control measures, can also lead to environmental contamination through leachate runoff. Additionally, products, particularly those containing plastics, can contribute to long-distance pollution through the movement of plastic debris. This is further illustrated by the significant anthropogenic flux of lead to the oceans, as highlighted by Viers et al. (2009), demonstrating how materials, products and waste can travel far beyond their points of origin and contribute to global environmental contamination.

    c. *Complex global value chains:* Modern supply chains are highly interconnected, with materials and products crossing multiple borders throughout their life cycle. For example, in 2024, the United States imported approximately 30% of its refined lead from countries such as Canada, the Republic of Korea, Mexico and Australia. While the U.S. produces and consumes lead-acid batteries (accounting for an estimated 86% of reported lead consumption), it also imports a significant volume of such batteries and exports around 20 million spent lead-acid batteries annually, primarily to Mexico for recycling (USGS, 2025a). Notably, end-of-life waste handling, particularly informal recycling of lead-acid batteries, is prevalent in low- and middle-income countries, where regulatory oversight and infrastructure are often inadequate to ensure worker safety and mitigate environmental pollution. Actions taken by a single actor at any point along the value chain, upstream or downstream, can have significant ripple effects on other actors across different regions of the world. Without comprehensive coordination, actions taken by individual actors may simply shift the problem elsewhere – potentially transforming it into new or more complex challenges. For example, as illustrated in the case of perfluorooctane sulfonic acid (PFOS) discussed by Blumenthal et al. (2022), the voluntary phase-out by 3M in 2002 led to a significant, unmet market demand for PFOS. This market gap was subsequently

[42] https://unece.org/fileadmin/DAM/env/documents/2012/air/Guidance_document_on_best_available_techniques_for_controlling_emissions_of_HM.pdf

filled by rapidly upscaling Chinese manufacturers, a development that took over two decades to address. Therefore, isolated efforts can inadvertently lead to unintended consequences, underscoring the need for integrated, globally aligned strategies.

Chapter 3. Options for enhanced international action & practical solution pathways to address pollution from lead, cadmium, arsenic and organotins

39. As highlighted in the previous chapter, lead, cadmium, arsenic and organotins have been long recognized as global concerns. In fact, during early negotiations on the Minamata Convention on Mercury, many countries proposed a broader scope to include other heavy metals and persistent inorganic pollutants, [43] aiming for a more integrated approach to managing toxic metals and metalloids. A key physical-chemical distinction between mercury and many other toxic metals and metalloids – one that likely influenced the early decision to limit the legally binding instrument to mercury – is that mercury's high volatility enables long-range atmospheric transport, making its emissions inherently transboundary in nature. In contrast, only certain forms and emission sources of lead, cadmium, arsenic and organotins have the physical and chemical characteristics that enable long-range atmospheric transport, thereby contributing to transboundary pollution. These typically include emissions from high-temperature industrial processes – such as metal smelting, coal and oil combustion, waste incineration and cement production – which release fine or ultrafine particulate matter and metal-bearing aerosols capable of remaining suspended for days to weeks. By contrast, larger or locally deposited particles from mechanical processes tend to settle near emission sites. Despite this, the persistence, re-suspension and potential for global dispersion of these metals justify coordinated international monitoring and control measures (He et al., 2023; Grotti et al., 2024).

40. Nevertheless, building on the broader considerations outlined in the previous chapter, it is timely to revisit the idea of a more integrated and internationally coordinated response to these substances. However, challenges in addressing these substances are not only technical but political and economic. The extraction, refining, use and recycling of these substances are deeply intertwined with national development models and the livelihoods of millions of workers and their communities.

41. To support the effective adoption and implementation of measures that may be perceived as threatening these economic and social structures – however rational from an environmental and human health standpoint – a practical pathway must be considered, that also accounts for economic realities and sector-specific risks. While enhancing international action may be considered a more medium-term objective, immediate action at the regional, national, local and sectoral levels is warranted to reduce exposure.

42. Efforts to tackle pollution and toxic emissions span multiple sectors and sources. Mining and smelting industries are major contributors to environmental contamination, often releasing heavy metals and other pollutants into surrounding ecosystems (Zeng et al., 2021; Qi et al., 2023; Shao et al., 2025). Informal recycling activities—such as recovering materials from used lead-acid batteries and electronic waste—pose serious health and environmental risks when hazardous substances are handled unsafely (Haefliger et al., 2009; UNEP, 2020a). Energy and industrial combustion processes also generate significant air pollution and residues, particularly where pollution controls are lacking, with far-reaching impacts on human health and ecosystems (Tian et al., 2015; Yang et al., 2024; Ma et al., 2025). In agriculture and food systems, contamination can result from pesticide and fertilizer residues, bioaccumulation, and irrigation with polluted water (Wang and Li, 2014; Mahfooz et al., 2020; Alengebawy et al., 2021; Naz et al., 2022; Rashid et al., 2023; Aslam et al.,

[43] E.g., UNEP(DTIE)/Hg/OEWG.2/INF/4 – Statement prepared by the African region at a regional preparatory meeting, available at https://minamataconvention.org/en/documents/statement-prepared-african-region-regional-preparatory-meeting; Earth Negotiations Bulletin (2009) Summary of the 25th Session of the UNEP Governing Council/Global Ministerial Environment Forum: 16-20 February 2009, available at https://enb.iisd.org/events/25th-session-unep-governing-councilglobal-ministerial-environment-forum-gc25gmef

2023; Su et al., 2025). The buildings, construction, and infrastructure sectors contribute through exposure to harmful substances in materials and the generation of contaminated waste during construction, renovation, or demolition (Jacobs et al., 2013; Chen and Zhou, 2020; Molla et al., 2021; Manoharan et al., 2021; Molla et al., 2025). Consumer products—including cosmetics, toys, cookware, and electronics—can create exposure risks during manufacturing and use when harmful chemicals are present and precautions are not taken (Guney et al., 2012; Sousa et al., 2018; Turner and Filella, 2021). Finally, waste management practices such as incineration and landfilling can release pollutants through emissions or leachate, especially when hazardous waste is not properly segregated or treated (Huang et al., 2009; Bouida et al., 2022; Huang et al., 2024; Mathews et al., 2024; Nguyen et al., 2024; Wang and Qiao, 2024).

43. Therefore, the present chapter proposes concrete response measures that take into account the key sectors concerned and the associated exposure risks, which Member States and other stakeholders could consider in the short- to medium-term. It then outlines a range of legally binding and non-legally binding options that may be considered when contemplating further globally coordinated action. Some of these options may, as relevant, serve as a framework within which the proposed measures may be integrated.

3.1 Practical solution pathways and sector specific response measures

44. Building on the major sources to the environment of lead, cadmium, arsenic and organotins highlighted previously, the below analysis aims to provide practical solution pathways with examples of possible response measures. Table 3 highlights where countries and stakeholders may take near-term action, where higher risks exist, and where further analysis may be required. The focus is on sectoral and risk-based, technically feasible and market-relevant actions, emphasizing opportunities for co-benefits, innovation and engagement with industry. The below analysis also indicates potential areas where further analysis and guidance by the Intergovernmental Science-Policy Panel on Chemicals, Waste and Pollution (ISP-CWP) could help countries prioritize interventions.

45. Embedding global action in a portfolio of coordinated actions that reflect economic realities and sector-specific risks can support governments balancing competing imperatives: safeguarding public health and the environment, maintaining industrial competitiveness, and sustaining employment and export revenues which may rely from metal-intensive sectors.

46. Such practical and politically viable pathway may therefore combine:
    - Sector-based approaches that address major exposure sources in ways that align with national economic contexts;
    - Incentives for transition, such as new market opportunities for safer products or access to international financing; and
    - Graduated measures that identify “quick wins” achievable without high economic or social costs, while laying the foundation for deeper reforms.

47. This approach recognizes that progress may emerge from a portfolio of coordinated actions that reflect economic realities and sector-specific risks.

Table 3. Indicative sectoral pathways and opportunities for action (*Note: The response measures outlined in the table below are indicative of possible short-, medium- or longer-term actions, which may vary depending on national circumstances, including existing control measures already implemented at sector or industry level.)*

Sector / Source	Relative exposure risk	Short-medium term response measures	Longer-term response measures	Market opportunities
Mining and smelting	High	• Promote co-benefit pollution control (multi-pollutant filters, improved dust capture). • Integrate emission standards into investment or concession agreements. • Establish hierarchy of sources, in which demand is met with existing stocks instead of through primary production. • Leach these substances out of ores prior to processing.	• Gradual modernization of smelters and tailings management. • Establish "responsible mining" certification schemes. • Restrict and phase out mining of virgin substances. • Restrict and phase out sale of these substances produced as by-products from mining other ores. • Require mining companies to store by-product in environmentally sound storage facilities.	• Access to green financing for cleaner production. • Market recognition through "clean metals" supply chains.
Informal recycling (lead-acid batteries, e-waste)	High	• Support transition from informal to formal recycling through microcredit, training and safe collection hubs. • Introduce extended producer responsibility (EPR).	• Regional recycling hubs with controlled processes. • Stricter enforcement of import/export controls. • Substitute alternative products and processes for those using or containing these substances.	• Job creation through formalization. • Public-private partnerships for circular economy models.
Energy and industrial combustion	High	• Upgrade emission controls in coal-fired plants and cement kilns. • Integrate heavy metal control into air-quality standards. • Establish emission reduction targets and timetables. • Improve energy efficiency in products and processes to lessen need to combust coal in electricity generation. • Improve energy conversion efficiency to reduce coal combustion. • Pre-treat coal before combustion to reduce emissions and releases via flue gas.	• Phase-in best available techniques (BAT) alongside mercury controls. • Incentivize low-emission fuels. • Transition to other energy sources (e.g., renewables) to reduce coal combustion.	• Multi-pollutant strategies supported by climate finance mechanisms.

Agriculture and food systems	Medium	• Restrict high-risk pesticide formulations and contaminated fertilizers. • Promote soil monitoring and crop substitution. • Increase vendor knowledge for products containing these substances.	• Utilize available, safer agrochemical alternatives. • Improve fertilizer quality control. • Restrict or ban pesticides containing these substances • Promote non-chemical alternatives such as integrated pest management and agroecology.	• Align with sustainable agriculture and food safety initiatives. • Access to green labeling and export markets.
Buildings, construction, and infrastructure	Medium	• Substitute lead and cadmium pigments in paints and PVC. • Update procurement standards for government projects. • Increase vendor knowledge for products containing these substances. • Ban or restrict use in products for which feasible alternatives are available. • Require low content of these substances in products for which alternatives free of these substances are not available. • Promote educational campaigns, including registration and labeling requirements to inform consumers.	• Integrate safer materials into green building codes. • Phase-out high-risk additives. • Levy disposal and production fees on products that contain these substances to encourage reduction in their use. • Prohibit or limit continued trade in products containing these substances for which feasible alternatives are available. • Support research and development for alternatives.	• Eco-labeling and public procurement preferences for "metal-safe" materials.
Consumer products (cosmetics, toys, cookware, electronics)	Medium to High	• Enforce limits for lead, cadmium, and arsenic in consumer goods. • Promote voluntary phase-out programmes. • Increase vendor knowledge for products containing these substances. • Ban or restrict their use in products for which feasible alternatives are available.	• Develop regional product safety standards. • Strengthen consumer awareness campaigns. • Develop labeling requirements for all products containing these substances to alert consumers. • Levy disposal and production fees on products that contain these substances to encourage reduction in their use.	• Certification and labeling to access "safe product" markets. • Enhanced brand reputation for manufacturers.
Waste management (including incineration and landfill leachate)	Medium	• Improve segregation and hazardous waste collection. • Ban open burning. • Increase knowledge for proper disposal methods. • Develop programmes to create easily accessible collection centers for consumers. • Develop interim storage guidelines for collection centers of products containing	• Modernize incineration facilities with heavy-metal filters. • Establish long-term remediation funds. • Ban the disposal in general waste stream of products that contain these substances by. designating waste containing these substances as hazardous. • Require vendors of products containing these substances to "take back" and properly dispose or recycle products after their useful life.	• Reduced liability and remediation costs. • Compliance with ESG and corporate sustainability standards.

		these substances regarding collection and transportation to final disposal or recycling facilities. • Develop hazardous waste management guidelines for waste containing these substances. • Establish waste management guidelines, including leachate collection and treatment technologies, for terminal storage and disposal of wastes containing them in hazardous waste landfills. • Sort wastes to reduce their hazardous content prior to incineration or landfilling.	• Monitor and collect leachate from landfills and introduce wastewater cleansing processes to remove these substances. • Require regular landfill inspections and employee training. • Create disincentives for poor landfill management by establishing comprehensive liability and compensation rules.	

48. Many of the measures presented in the above table align naturally with countries' existing priorities – such as sustainable industrialization, waste minimization, green jobs and food safety. They also resonate with the vision emerging across the broader chemicals and waste agenda: achieving "safe products without exposure risks". This framing provides a unifying narrative that can:
   - Encourage coordination with related agendas, including plastics, circular economy, and pollution prevention; and
   - Mobilize investment by demonstrating market and social benefits.

49. Lastly, recognizing the establishment of the Intergovernmental Science-Policy Panel on Chemicals, Waste and Pollution and its objective to "strengthen the science-policy interface to contribute to the sound management of chemicals and waste and pollution prevention [for the protection of human health and the environment]", this new panel presents an important opportunity to assess substances such as lead, cadmium, arsenic and organotins. Given the long-standing awareness of the risks posed by these substances, the panel's assessments could focus on solution-oriented aspects, including: technological, social and economic transition pathways; sector-specific interventions; and the identification of best available techniques and best environmental practices, taking into account multi-pollutant control strategies. These assessments would be policy-relevant and grounded in scientific evidence, offering actionable insights for decision-makers. However, any such assessment would be subject to the approval of the panel's work programme by its Plenary, the governing body. As the panel is still in the process of finalizing its rules and procedures, it may take time before such assessments can be initiated. Furthermore, additional efforts will be required to ensure that the findings of these assessments are effectively translated into concrete policy and action once the assessments are finalized.

3.2 Policy instruments for enhanced global action: legally and non legally binding options

50. It may be essential to first establish a common policy objective as the foundation for future enhanced international action on these substances. The specific form that such action might take – whether legally binding instruments, non-binding arrangement[44] or voluntary measures and initiatives – may be considered a secondary question, guided by the notion that "form follows function". Accordingly, the present sub-section explores options based on two potential policy objectives: (a) advancing a unified global action framework – developing integrated international action through a single, cohesive framework to address these substances, and (b) enhancing collective approaches – strengthening international action through coordinated, individual measures tailored to specific aspects of these substances that may collectively cover the full scope of these four substances. For each policy objective, the potential forms are considered.

51. These options, outlined in Table 4, are described in terms of their potential formats; feasibility, taking into account existing measures and initiatives; and anticipated effectiveness, focusing on scope of coverage and excluding compliance and enforcement considerations. The analysis does not present the totality of the many instruments and approaches that might be used to address the challenges of lead, cadmium, arsenic and organotins.

52. The sequence in which the options are presented does not imply any prioritization. Moreover, the options are not mutually exclusive; instead, they may be pursued in parallel or implemented sequentially. For instance, in the case of mercury, the voluntary Global Mercury Partnership was initially established to enable immediate risk mitigation efforts, which later paved the way for the adoption and implementation of the legally binding Minamata Convention on Mercury. Moreover, enhancing international action should not be seen as a substitute for regional, national or sectoral measures, as discussed above. On the contrary, such measures and initiatives should be further

[44] They refer to non-legally binding tools such as agreements, principles, declarations, resolutions, codes of conduct, guidelines, strategies, action plans, and fiscal policies. While not enforceable by law, these instruments establish norms and expectations set by governments and intergovernmental organizations.

developed to complement and support strengthened international efforts. Conversely, while developing and strengthening regional, national and sectoral measures represent essential milestones, they are unlikely to fully replace the need for strengthened international action, particularly for the reasons outlined in Section 2.4.

53. The options presented here are not only technical pathways – they represent strategic policy opportunities for Member States to determine the scale and pace of global action. Decisions made by Member States can shape a trajectory toward a coherent, sustainable framework for reducing exposure to these substances and for the sound management of chemicals and waste more broadly.

Table 4. Overview of options for further global action to address lead, cadmium, arsenic and organotins, including a brief description, feasibility and effectiveness.

Option	Feasibility	Effectiveness
GLOBAL LEGALLY-BINDING APPROACHES		
Option 1 ─ Advancing Unified Global Action Framework via Multilateral Agreements: In addition to a free-standing convention, one may consider the approach of a protocol: a legally binding instrument that is usually, but not always, a subsidiary instrument to an existing treaty or convention[45].	A protocol to the Minamata Convention may be preferable to directly amending the Convention to include substances such as lead, cadmium, arsenic and organotins. The latter could lead to (1) "opening up" the entire Convention to renegotiation, and (2) having two substantively different forms of the Convention in force at the same time (subject to the ratification status by different Parties), along with the complexity that certain Parties may face while transposing the amendment into their domestic legislation for the implementation. It can also leverage existing institutions, mechanisms, expertise and capacities under the Minamata Convention to enhance cost-efficiency and foster synergies through the implementation of multi-pollutant control strategies. Additionally, protocols can allow for different membership from their parent convention, as demonstrated by the Kiev Protocol on Pollutant Release and Transfer Registers. This more flexible arrangement may allow Member States to choose the timing of ratification, given the potential complexity of transposing international treaties into their domestic legislation – especially when compared to adopting an amendment to the convention. Such flexibility can help accommodate varying national legislative processes and capacities, reduce political and administrative pressure, and ultimately encourage broader participation and more effective implementation over time. Protocols are often explicitly authorized by their parent conventions[46].	A key consideration for both a new free-standing convention and a potential toxic metals protocol under the Minamata Convention is the ability to comprehensively address all relevant aspects following a life-cycle approach, with strong political commitment. Furthermore, the legally binding nature of such instruments provides a solid legal foundation and accountability, financial mechanism for implementation, and support for developing countries. Without this support, meaningful progress in mitigating the risks posed by these substances may remain out of reach for many nations.

[45] According to the United Nations Treaty Collection Treaty Reference Guide, "the term 'protocol' is used for agreements less formal than those entitled 'treaty' or 'convention' […] A protocol as a supplementary treaty is an instrument which contains supplementary provisions to a previous treaty." For example, the Vienna Convention provides a framework for international cooperation to protect the ozone layer, while the Montreal Protocol mandates the phase-out of ozone-depleting substances and their alternatives. By negotiating and adopting a supplementary protocol, States Parties to the original convention accomplished their policy goals without the necessity of opening up the original convention to amendment.

[46] For instance, the Montreal Protocol was developed pursuant to Article 8 of the Vienna Convention.

	However, in other cases, protocols have been adopted even without express provisions in the parent treaty [47]. The Minamata Convention for instance, despite not containing any provisions regarding the adoption of protocols, could still serve as a foundation for a supplementary protocol. To enable the development of a new protocol under the Minamata Convention, it may be necessary to amend the Convention's objectives to encompass other toxic metals and metalloids. This expansion would need to remain aligned with the Convention's overarching purpose, ensuring coherence while broadening its scope to address additional substances of concern.	
Option 2 — Enhancing Collective Approaches via Expanding Existing Legally Binding Instruments: This option may involve listing additional relevant substances under the Basel, Rotterdam, and Stockholm Conventions (e.g. under the Basel Convention, explicit listing of organotin-related waste and expansion of technical guidelines to cover all relevant waste streams; under the Rotterdam Convention, consideration for listing of all compounds of lead, cadmium arsenic and organotins, thereby subjecting them to the PIC procedure; under the Stockholm Convention, consideration of certain organotin compounds as potential candidates of persistent organic pollutants). It could also involve broadening the membership of the Heavy Metals Protocol under the CLRTAP to enable global participation. This option may also extend beyond the scope of legally binding instruments within the chemicals and waste domain by exploring relevant frameworks in other fields, such as biodiversity and climate change.	The Basel, Rotterdam and Stockholm Conventions contain relevant provisions that allow for the inclusion of new substances or waste streams within their scope, and there are numerous precedents for such listings. However, the listing process can be complex and politically sensitive. Additionally, there are precedents for protocols under the UNECE framework allowing for open membership, such as the Kiev Protocol on PRTR, which is open to global participation beyond the UNECE region. This sets a potential precedent for expanding the membership of the Heavy Metals Protocol under the CLRTAP, enabling broader international engagement and enhancing its relevance as a global instrument for addressing toxic metals and metalloids. However, it is important to recognize that while the Kiev Protocol is formally open to global membership, its actual membership remains relatively limited to date. This highlights the practical challenges of expanding participation beyond the original regional scope, even when legal provisions allow for broader inclusion.	This option can provide legal foundation and accountability, financial mechanism for implementation, and support for developing countries on specific aspects of these substances. However, ensuring that all relevant aspects are adequately addressed across a diverse set of independent legal instruments – each with its own scope, governance structure, and procedural dynamics – can be complex and resource intensive. This fragmentation may hinder coherence and limit the overall effectiveness of efforts to comprehensively manage these substances.
GLOBAL VOLUNTARY APPROACHES		
Option 3 — Advancing a Unified Global Action Framework via a High-Level Political Declaration: This option may take place along with a global plan of implementation, which can raise awareness among governments and stakeholders of the challenges posed by these substances, strengthen political will, and establish mechanisms and processes to facilitate	Many precedents exist for such an approach. One possible starting point could be a resolution adopted by UNEA, which may either initiate negotiations directly under its auspices or invite other international forums, such as the International Conference under the Global Framework on Chemicals (noting that recent discussions confirm that lead in particular	This option offers the potential for a comprehensive life-cycle approach, with a level of political commitment. However, its non-legally binding nature means that countries and stakeholders would not be subject to formal obligations, including establishment of a sustainable and predictable

[47] CLRTAP, for example, contains no reference to protocols, yet its Parties have successfully developed and adopted eight substance-specific protocols, including the 1998 Aarhus Protocol on Heavy Metals. Similarly, the 1972 IMO Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) did not include provisions for protocols but was later revised through the adoption of the more restrictive 1996 London Protocol.

coordinated, comprehensive international efforts among key stakeholders.	is of interest to stakeholders in this community), to consider doing so. Ensuring adequate resources would be essential to support this process. Recognizing the Minamata Convention as a model for adopting a holistic life-cycle approach to addressing a heavy metal – through its institutions, mechanisms, expertise, and capacities, as well as parallels across economic sectors and lessons learned – it may be appropriate for Parties and stakeholders to the Convention to be actively engaged in the process, or to be invited to initiate consideration of such a process. Additionally, establishing synergies between any new or expanded measures and the WHO's Global Action Plan on lead would be important to promote coherence and maximize impact. A high-level political declaration can be modelled on existing examples. As their development can sometimes be as resource intensive as negotiation of multilateral agreements, it may be wiser to consider a high-level political declaration and associated global plan of implementation for toxic metals and metalloids in general.	financial mechanism—potentially resulting in uncertain funding and implementation.
Option 4 – Advancing Unified Global Action Framework via a Voluntary Partnership or Mechanism: This option can take the form of strategic partnerships/mechanisms to help identify specific needs, available resources and gaps, and could help coordinate and prioritize the provision of such assistance to enhance its effectiveness. It may also involve recognizing these substances as an issue of concern under the Global Framework on Chemicals.	*Global voluntary Partnership:* Many precedents exist for such an approach. A potential new partnership on these four substances, or on toxic metals and metalloids more broadly, could be established as a standalone initiative or integrated into the UNEP Global Mercury Partnership[48]. For example, UNEA could mandate UNEP (for instance through the secretariat of the Global Mercury Partnership) or invite other international forums, such as the Global Framework on Chemicals, to lead a process towards establishing such a partnership. Additionally, several partnerships such as the Global Alliance to Eliminate Lead Paint and the Partnership for a Lead-free Future already exist, focusing on specific aspects of lead. Therefore, the establishment of a new partnership would necessitate effective coordination mechanisms with existing partnerships to avoid duplication, foster synergies and ensure comprehensive coverage of relevant issues.	*Global voluntary Partnership:* In addition to the broad scope a partnership could adopt to comprehensively address all relevant aspects of these substances, or toxic metals and metalloids in general, strategic implementation of the partnership could enhance the effectiveness of voluntary efforts by individual participants and facilitate more efficient use of bilateral, multilateral, and private sector assistance. As with the high-level political declaration and global plan of implementation approach, effective implementation of a partnership would require a dedicated secretariat. However, its non-legally binding nature means that countries and stakeholders would not be subject to formal obligations, including establishment of a sustainable and predictable financial mechanism – potentially resulting in uncertain funding and implementation.
	Issues of concern under the Global Framework on Chemicals: While the process for accepting new issues of concern under the Global Framework on Chemicals is yet to be fully	*Issues of concern under the Global Framework on Chemicals:* As the Global Framework on Chemicals is still in the early stages of implementation, the effectiveness of listing new

[48] Initiated in 2005 and with close to 300 partner organizations from governments, intergovernmental organizations, civil society organizations, industry and academia, the Global Mercury Partnership focuses on supporting timely and effective action on mercury, providing state of the art knowledge and science, and raising awareness towards global action mercury. It comprises eight areas of work, which represent sectors that use mercury or process raw materials that contain mercury, as well as key themes in mercury management and science.

	implemented at the first and subsequent International Conferences, it is expected that new issues can be added over time. In fact, ongoing efforts are exploring the broader inclusion of lead as a new issue of concern, alongside lead in paint, which is already recognized and will be further considered. UNEA may invite the International Conference of the Global Framework on Chemicals to consider substances such as lead, cadmium, arsenic, and organotins as new issues of concern – similar to how the UNEP Governing Council previously invited the International Conference on Chemicals Management (ICCM), the predecessor of the International Conference, to consider lead (see Annex 1). However, detailed submissions will need to be prepared, including on why the Framework is best placed to advance the issue in addition to the necessary scientific, policy and implementation information required for the International Conference to formally consider and accept the proposed issues.	issues of concern under the Framework remains to be seen. The practical impact of such listings will depend on how these mechanisms, including resource mobilization, are operationalized and supported by participating stakeholders. This constraint could affect the Framework's ability to effectively support new issues of concern, mobilize technical assistance, and ensure meaningful implementation from developing countries, thereby impacting its overall effectiveness.
Option 5 - Enhancing Collective Approaches via Soft Law or Voluntary Best Practices: This option may involve the development of best practices through model laws, codes of conduct and guidelines, standards, and third-party labelling and certification schemes, and may take the form of soft law when driven by governments or remain voluntary when initiated by other stakeholders. Two types of measures are considered here: codes of conduct and third-party labelling and certification schemes.	<u>*Codes of conduct*</u>: Can be designed for use within the implementation of national legislation and serve as voluntary standards for corporate practice in jurisdictions lacking relevant legislation. They can also be developed by individual companies or industries at national, regional or international level. Large corporations with sufficient market influence may require their suppliers to adhere to their internal codes of conduct, thereby extending standards across supply chains. They may also initially be led or catalyzed by governments or intergovernmental organizations and subsequently transferred to industry for implementation or further refinement[49]. Many precedents exist for such an approach, such as the *International Code of Conduct on Pesticide Management[50],* which could be used as a model. For example, UNEA could mandate UNEP or establish an ad hoc open-ended working group to initiate the development of a draft code of conduct, in consultation with governments, stakeholders, and relevant standard-setting organizations such as the International Organization for Standardization (ISO). Alternatively, it could	<u>*Codes of conduct:*</u> Sector-specific codes of conduct and technical guidelines may be needed due to the diversity of actors and conditions. Their flexibility allows for gradual adoption and regular updates. However, ensuring broad coverage requires coordination, which can be challenging, and the lack of formal obligations or financial mechanisms may lead to uncertain implementation – especially in sectors with informal or small-scale actors lacking capacity and resources.

[49] e.g., the International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold, and the Global Industry Standard on Tailings-Management

[51] Under Responsible Care, participating companies commit to proactively supporting safe chemicals management, improving environmental, health, and safety performance, enhancing facility security, and promoting life cycle-oriented, data-driven best practices. They also pledge to engage with stakeholders transparently and contribute to sustainability through innovation. Responsible Care is currently implemented by 64 chemical associations across more than 70 economies worldwide.

	invite other international forums, such as the Global Framework on Chemicals. to lead the process. Technical guidelines could be developed and adopted alongside the code or introduced at a later stage. Amongst voluntary codes by industry, *Responsible Care* was developed by the chemicals sector as a global performance initiative[51], along with many other examples led by individual industries (such as the Consolidated Mining Standard Initiative,[52] led by ICCM and the ZDHC Manufacturing Restricted Substances List,[53] led by the ZDHC Foundation) and companies (such as Apple Regulated Substances Specification [54] and Volvo Group Environmental Standards[55]).	
Option 6 - Market instruments	*Voluntary standards through labelling and certification schemes:* Governments, intergovernmental organizations, civil society and the private sector could also collaborate to establish or expand eco-labeling and certification programmes as market-based approaches to set voluntary standards for specific aspects related to lead, cadmium, arsenic and organotins. Governments, intergovernmental organizations, civil society and the private sector could also collaborate to establish or expand eco-labeling and certification programmes as market-based approaches to set voluntary standards for specific aspects related to lead, cadmium, arsenic and organotins. According to the ISO, eco-labeling is defined as "a voluntary, multiple-criteria-based, third-party programme that awards a license authorizing the use of environmental labels on products, indicating overall environmental preferability within a product category based on life cycle considerations". Recognizing the marketing advantages, many manufacturers actively support and participate in such programmes. Similarly, certification programmes, administered by government agencies or independent third parties, assure consumers that products or processes meet established	*Voluntary standards through labelling and certification schemes:* Eco-labeling and certification programmes can influence consumer behavior, public procurement and retailer choices, but face challenges in coordination, transparency and credibility. Their effectiveness depends on government support, harmonization across initiatives, and clear, reliable standards to avoid confusion and build trust.

[51] Under Responsible Care, participating companies commit to proactively supporting safe chemicals management, improving environmental, health, and safety performance, enhancing facility security, and promoting life cycle-oriented, data-driven best practices. They also pledge to engage with stakeholders transparently and contribute to sustainability through innovation. Responsible Care is currently implemented by 64 chemical associations across more than 70 economies worldwide.

	standards, such as those related to fair trade or environmental sustainability. These standards may be set by governments, international organizations, or independent certifying bodies. Several existing eco-labeling standards already consider whether production processes result in emissions of pollutants or whether products contain toxic chemicals. For example, the Global Ecolabelling Network (GEN), an international non-profit association founded in 1994, connects third-party environmental labeling organizations across countries. GEN has encouraged its members to include prohibitions on mercury in paints and electronic components as part of their core criteria, offering a precedent for standards addressing these substances.	
NATIONAL REGULATORY MEASURES		
Option 7 – National regulatory measures	As highlighted in Chapter 2, a range of measures and initiatives has been implemented at the regional and national levels to address these substances, including legally binding instruments – such as bans or restrictions (including the setting of threshold values in products), market authorizations, mandatory national standards for specific applications, and export notifications for certain substances. Regarding arsenic, some countries and regions have adopted legally binding instruments to restrict its use or presence in one or more product categories, including anti-fouling systems, treatment of industrial waters, wood preservatives, fertilizers, animal feeds, toys, packaging material, perfume and cosmetics, and/or foodstuffs. Guideline values for arsenic levels in different exposure media (e.g., in occupational settings) have also been established in a number of countries (UNEP (2022b)). Regarding cadmium, approaches have been varied. A number of countries and regions have taken actions to legally restrict, ban or set mandatory national standards in specific uses, such as restrictions and/or bans on its use in mixtures and articles produced from synthetic organic polymers, food-related items, specific electrical and electronic products and by setting legal limits for its unintentional presence in different fertilizers. In addition, a large number of countries have looked at emissions and exposure media, and set up guideline values for different exposure media (UNEP (2020b, 2022c)).	National legislative and regulatory measures play a significant role and have notably enabled the phase-out of lead in fuel through coordinated efforts. However, as noted in Chapter 2, current responses remain too fragmented to fully address the global challenges posed by these substances and hence reduce the associated risks.

	For lead, many countries and regions have taken actions to legally restrict or ban it in a wide variety of specific uses. Lead paint regulations have been adopted and implemented in many countries. A large number of countries have looked at releases from anthropogenic sources and exposure media that are not lead-specific, and some countries have set up guideline values for different exposure media that are either legally binding or serve as recommended guidance values (UNEP (2022d)). Finally, as for organotins, many countries at the national and regional levels have taken action to address tributyltin in anti-fouling paints on ships before or in response to the AFS Convention. Some countries and regions have gone further and set legal restrictions on more organotins in a wider range of uses (UNEP 2022e). Existing instruments and approaches may be used as models to inform further action by countries at the national level. Both global legally binding and non-legally binding approaches can further encourage and support the development and strengthening of national regulatory frameworks including through capacity building to ensure effective implementation and sustainability.	

Chapter 4. Conclusions and potential ways forward

54. This report underscores the urgent need for enhanced international action to address the global risks posed by lead, cadmium, arsenic and organotins, given the widespread and likely growing exposure and associated societal burden. Existing assessments reveal that current measures are insufficient to fully mitigate their long-term impacts on human health, the environment and society. While these measures offer a valuable foundation, future efforts need to adopt a life-cycle approach across all relevant industry and economic sectors covering both supply and demand, as well as trade and end-of-life aspects, recognizing both sector-specific differences and cross-sectoral commonalities to enable integrated and effective mitigation strategies. International cooperation and coordination would be essential to ensure consistency and impact across regions and sectors.

55. A key recommendation for the next step is to establish a common policy objective to effectively guide future action. The form of this action, whether through legally binding instruments, non-binding/soft law arrangements, voluntary initiatives, or national regulation based on countries' own determinations, may be determined based on the intended policy objective. To support the deliberation by Member States, there are three potential longer term policy objectives: (1) advancing a unified global action framework, (2) enhancing collective approaches, building upon measures tailored to specific aspects of these elements, and (3) national measures including nationally determined regulation. Each objective includes a range of legally binding, non-binding/soft law and voluntary options. These policy options could be complemented by contributions from the newly established Intergovernmental Science-Policy Panel on Chemicals, Waste and Pollution. Future efforts should be aligned with existing measures and initiatives to avoid duplication and maximize impact.

56. Looking ahead, Member States may wish to deliberate on the ambition level of their policy objectives, building on their national and regional circumstances and existing gaps, and then consider the most suitable approaches to realize such policy objectives, including the possibility of combined, phased approaches that associate immediate actions with longer-term strategies.

57. Responding to the need to mitigate environmental and health risks arising from exposure to these substances from key sources, Member States may wish to consider how the response measures presented in the report may be implemented as a first step of immediate action at regional, national, local and/or sectoral levels. In addition, drawing on the experience of the Minamata Convention, a voluntary partnership or mechanism could be initiated promptly to help intensify immediate efforts in addressing the issue, alongside the development of the WHO Global Action Plan on Lead. Over the longer term, investing in a legally binding or soft law approach may be critical to ensure a comprehensive and lasting solution. Such an approach can be essential to ensure sustained progress and a coherent global response to the challenges posed by these toxic substances.

58. The global community has successfully phased out lead in gasoline and curbed mercury use – demonstrating that coordinated action delivers measurable results. The same momentum could prevent avoidable health and environmental impacts and associated economic losses, while taking advantage of new markets and other economic opportunities that solutions present.

References

Adams, W.A., Xu, Y., Little, J., Fristachi, A.F., Rice, G., Impellitteri, C.A. (2011). Predicting the migration rate of dialkyl organotins from PVC pipe into water. Environ Sci Technol 45(16):6902–6907. doi:10.1021/es201552x.

Airaksinen, R., Rantakokko, P., Turunen, A.W., Vartiainen, T., Vuorinen, P.J., Lappalainen, A., Vihervuori, A., Mannio, J., Hallikainen, A. (2010) Organotin intake through fish consumption in Finland. Environ Res 110(6):544–547. doi:10.1016/j.envres.2010.06.004

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M.-Q. (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. *Toxics*, *9*(3), 42. https://doi.org/10.3390/toxics9030042.

Alsabri, A., Al-Ghamdi, S.G. (2020). Carbon footprint and embodied energy of PVC, PE, and PP piping: perspective on environmental performance. *Energy Rep* 2020; 6: 364–370.

Amec Foster Wheeler and European Commission (2017). Study on the Cumulative Health and Environmental Benefits of Chemical Legislation. Final report. Luxembourg: EU Publications Office ISBN 978-92-79-71775-8. DOI: 10.2779/070159. https://op.europa.eu/en/publication-detail/-/publication/b43d720c-9db0-11e7-b92d-01aa75ed71a1/language-en.

Armstrong, J. (1998). Global Benefits and Costs of the Montreal Protocol. In: Le Prestre, P.G., Reid, J.D., Morehouse, E.T. (eds) Protecting the Ozone Layer. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-5585-8_26

Aslam, A., Naz, A., Shah, S. S. H., Rasheed, F., Naz, R., Kalsom, A., Mukhtar, N., Niaz, A., Aftab, M., Rasheed, I., Haq, M. A. U., Arif, M., Sattar, A., & Hussain, S. (2023). Heavy metals contamination in vegetables irrigated with wastewater: a case study of underdeveloping regions of Pakistan. *Environmental geochemistry and health*, *45*(12), 8911–8927. https://doi.org/10.1007/s10653-023-01662-0.

Ateia, M., Sigmund, G., Bentel, M. J., Washington, J. W., Lai, A., Merrill, N. H., Wang, Z. (2023). Integrated data-driven cross-disciplinary fraemwork to prevent chemical water pollution. *One Earth* 6(8), 952-963. DOI : 10.1016/j.oneear.2023.07.001.

Balta, I., Lemon, J., Gadaj, A., Cretescu, I., Stef, D., Pet, I., Stef, L., McCleery, D., Douglas, A., Corcionivoschi, N. (2025). The interplay between antimicrobial resistance, heavy metal pollution, and the role of microplastics. *Frontier in Microbiology* 16. DOI: 10.3389/fmicb.2025.1550587.

Bazzano, A., Cappelletti, D., Udisti, R., Grotti, M. (2016). Long-range transport of atmospheric lead reaching Ny-Ålesund: Inter-annual and seasonal variations of potential source areas. *Atmospheric Environment* 139, 11-19. DOI: 10.1016/j.atmosenv.2016.05.026.

Blumenthal, J., Diamond, M. L., Hoffmann, M., Wang, Z. (2022). Time to break the "lock-in" impediments to chemicals management. *Environmental Science & Technology* 56(7), 3863-3870. https://doi.org/10.1021/acs.est.1c06615

Boraiko, C., Batt, J. (2005). Evaluation of employee exposure to organic tin compounds used as stabilizers at PVC processing facilities. Journal of Occupational and Environmental Hygiene, 2(1), 73–76. DOI: 10.1080/15459620590906810.

Bouida, L., Rafatullah, M., Kerrouche, A., Qutob, M., Alosaimi, A. M., Alorfi, H. S., & Hussein, M. A. (2022). A Review on Cadmium and Lead Contamination: Sources, Fate, Mechanism, Health Effects and Remediation Methods. *Water*, *14*(21), 3432. https://doi.org/10.3390/w14213432.

Chen, C., Chen, L., Yao, Y., Artigas, F., Huang, Q., & Zhang, W. (2019). Organotin release from polyvinyl chloride microplastics and concurrent photodegradation in water: Impacts from salinity, dissolved organic matter, and light exposure. *Environmental Science & Technology, 53*(18), 10741-10752. https://doi.org/10.1021/acs.est.9b03428.

Chen, Y., Zhou, Y. (2020). The contents and release behavior of heavy metals in construction and demolition waste used in freeway construction. *Environmental Science and Pollution Research*, 27(1), 1078-1086. DOI: 10.1007/s11356-019-07067-w.

Chen, W., Gong, Y., McKie, M., Almuhtaram, H., Sun, J., Barrett, H., Yang, D., Wu, M., Andrews, R. C., & Peng, H. (2022). Defining the Chemical Additives Driving *In Vitro* Toxicities of Plastics. *Environmental science & technology*, *56*(20), 14627–14639. https://doi.org/10.1021/acs.est.2c03608.

Chilvers, D.C., Peterson, P.J. (1987). Global Cycling of Arsenic. In Lead, Mercury, Cadmium and Arsenic in the Environment SCOPE 31, Ch. 7. Hutchinson, T.C., Meema, K.M., Eds. Chichester, England: John Wiley & Sons. https://scope.dge.carnegiescience.edu/SCOPE_31/SCOPE_31_2.12_Chapter17_279-301.pdf

Choi, M., Moon, H-B., Choi, H-G. (2012). Intake and potential health risk of butyltin compounds from seafood consumption in Korea. Arch Environ Contam Toxicol 62(2):333–340. doi:10.1007/s00244-011-9688-5.

Chowdhury, R., Ramond. A., O'Keeffe. L.M., Shahzad, S., Kunutsor, S.K., Muka, T., Gregson, J., Willeit, P., Warnakula, S., Khan, H., Chowdhury, S., Gobin, R., Franco, O.H., Di Angelantonio, E (2018). Environmental toxic metal contaminants and risk of cardiovascular disease: systematic review and meta-analysis. BMJ. 2018 Aug 29;362:k3310. doi: 10.1136/bmj.k3310. PMID: 30158148; PMCID: PMC6113772.

Cläsgens, C., Schwank, T., Pitzke, K. (2024). Occupational exposure to organotin substances: Development of a liquid chromatographic separation method for 11 organotin compounds in workplace air samples via HPLC-ICP-MS. *Journal of Chromatography A*, 1718, 464695. DOI: 10.1016/j.chroma.2024.464695.

Ericson, B., Landrigan, P., Taylor, M.P., Frostad, J., Caravanos, J., Keith, J., Fuller, R. (2016). "The Global Burden of Lead Toxicity Attributable to Informal ULAB Processing." Annals of Global Health, 82(5), 686-699

Ericson, B., Hu, H., Nash, E., Ferraro, G., Sinitsky, J., Taylor, M. P. (2021). Blood lead levels in low-income and middle-income countries: a systematic review. *The Lancet Planetary Health*, 5(3), e145-e153. DOI: 10.1016/S2542-5196(20)30278-3.

FAO and ITPS (2015). Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Fent, K. (1996a) Ecotoxicology of organotin compounds. Crit Rev Toxicol 26(1):1–117. doi:10.3109/10408449609089891.

Fent, K. (1996b) Organotin compounds in municipal wastewater and sewage sludge: contamination, fate in treatment process and ecotoxicological consequences. Sci Total Environ 185(1–3): 151–159. doi:10.1016/0048-9697(95)05048-5.

Forsyth, D.S., Jay, B. (1997). Organotin leachates in drinking water from chlorinated poly(vinyl chloride) (CPVC) pipe. Appl Organomet Chem 11(7):551–558. doi:10.1002/(SICI)1099-(199707)11: 7\551:AID-AOC606[3.0.CO;2-0

Fristachi, A., Xu, Y., Rice, G., Impellitteri, C. A., Carlson-Lynch, H., & Little, J. C. (2009). Using probabilistic modeling to evaluate human exposure to organotin in drinking water transported by polyvinyl chloride pipe. *Risk Analysis, 29*(11), 1615-1628. https://doi.org/10.1111/j.1539-6924.2009.01307.x.

Gibb, H. J., Barchowsky, A., Bellinger, D., Bolger, P. M., Carrington, C., Havelaar, A. H. et al. (2019). Estimates of the 2015 global and regional disease burden from four foodborne metals – arsenic, cadmium, lead and methylmercury. *Environmental Research* 174:188-194. https://doi.org/10.1016/j.envres.2018.12.062.

Gillieatt, B. F., Voleman, N. V. (2024). Unravelling the mechanisms of antibiotic and heavy metal resistance co-selection in environmental bacteria. *FEMS Microbiology Reviews* 48(4), fuae017. DOI: 10.1093/femsre/fuae017.

Grotti, M., Ardini, F., Vecchio, M. A., Mataloni, M., Bertinetti, S., Bruschi, F., Moroni, B., Cappelletti, D., Hobin, K., Vanhaecke, F. (2024). New insights into the sources of atmospheric lead reaching the Arctic by isotopic analysis of PM10 atmospheric particles and resuspended soils. *Atmospheric Environment*, **330**, 120541. DOI: 10.1016/j.atmosenv.2024.120541.

Guerin, T., Sirot, V., Volatier, J.L., Leblanc, J.C. (2007) Organotin levels in seafood and its implications for health risk in high-seafood consumers. Sci Total Environ 338(1–3):66–77. doi:10.1016/j. scitotenv.2007.08.027

Guney, M., Zagury, G. J., Dogan, N., & Oncel, M. (2012). *Toxicity of metals and metal mixtures: Review of heavy metal content in toys and children's jewelry in North America. Environmental Science & Technology, 46*(9), 4265–4274. https://doi.org/10.1021/es203470x

Haefliger, P., Mathieu-Nolf, M., Lociciro, S., Ndiaye, C., Coly, M., Diouf, A., Faye, A. L., Sow, A., Tempowski, J., Pronczuk, J., Filipe Junior, A. P., Bertollini, R., & Neira, M. (2009). Mass lead intoxication from informal used lead-acid battery recycling in dakar, senegal. *Environmental health perspectives*, *117*(10), 1535–1540. https://doi.org/10.1289/ehp.0900696

Han, F. X., Su, Y., Monts, D. L., Plodinec, M. J., Banin, A., & Triplett, G. E. (2003). Assessment of global industrial-age anthropogenic arsenic contamination. Naturwissenschaften 90:395–401. https://doi.org/10.1007/s00114-003-0451-2

He, L., Wang, S., Liu, M., Chen, Z., Xu, J., Dong, Y. (2023). Transport and transformation of atmospheric metals in ecosystems: A review. *Journal of Hazardous Materials Advances*, 9, 100218. DOI: 10.1016/j.hazadv.2022.100218.

Heng, Y. Y., Asad, I., Coleman, B., Menard, L., Benki-Nugent, S., Hussein Were, F., Karr, C. J., McHenry, M. S. (2022). Heavy metals and neurodevelopment of children in low and middle-income countries: A systematic review. *PLoS ONE*, 17(3), e0265536. DOI: 10.1371/journal.pone.0265536.

Hou, D., Jia, X., Wang, L., Mcgrath, S. P., Zhu, Y.-G., Hu, Q., Zhao, F.-J., Bank, M. S., O'Connor, D., Nriagu, J. (2025). Global soil pollution by toxic metals threatens agriculture and human health. *Science* 388(6744), 316-321. DOI: 10.1126/science.adr5214.

Huang, J.-H., Ilgen, G., Vogel, D., Michalzik, B., Hantsch, S., Tennhardt, L., et al. (2009). Emissions of inorganic and organic arsenic compounds via the leachate pathway from pretreated municipal waste materials: A landfill-reactor study. Environmental Science & Technology, 43(23), 9081–9087. https://doi.org/10.1021/es901605q.

Huang, Z., Cui, J., Boré, A., Ma, W., Zhang, Z., Qiao, Z., Lou, Z., Fellner, J. (2024). Health risk assessment of municipal solid waste incineration emissions based on regression analysis. *Eco-Environment & Health, 3*(3), 338–346. https://doi.org/10.1016/j.eehl.2024.01.009

Huang, W., Zhang, C., Zhu, B., Liu, X., Xiao, H., Liu, S., Shao, H. (2025). Systematic evaluation of plant metals/metalloids accumulation efficiency: a global synthesis of bioaccumulation and translocation factors. Front Plant Sci. 2025 Jun 5;16:1602951. doi: 10.3389/fpls.2025.1602951. PMID: 40538879; PMCID: PMC12178126.

Hughes, A (2021). Building and constructions plastic market – an Analysis. *Reinforc Plast* 2021; 65(4): 194–198.

IEA-International Energy agency (2021). The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions, Licence: CC BY 4.0.

IHME—Institute for Health Metrics and Evaluation (2016). Global Lead Exposure. In: GBD Compare [website]. Seattle (WA): Institute for Health Metrics and Evaluation, University of Washington. https://vizhub.healthdata.org/gbd-compare/

IHME-Institute for Health Metrics and Evaluation (2024). Lead exposure-Level 3 risk. Seattle: University of Washington; 2024 (https://www.healthdata.org/research-analysis/diseases-injuries-risks/factsheets/2021-lead-exposure-level-3-risk).

Jacobs, D. E., Clickner, R. P., Zhou, J. Y., Viet, S. M., Marker, D., Rogers, J. W., … & Farfel, M. (2013). Lead and Other Heavy Metals in Dust Fall from Single-Family Homes during Demolition. *Environmental Health Perspectives*, 121(4), 377–382. DOI: 10.1289/ehp.1205296.

Jones-Lepp, T.L., Varner, K.E., Hilton, B.A. (2001). Speciation and detection of organotins from PVC pipe by micro-liquid chromatographyelectrospray-ion trap mass spectrometry. Appl Organomet Chem 15(12):933–938. doi:10.1002/aoc.246.

Kerret, D., Gray, G. M. (2007). What do we learn from emissions reporting? Analytical considerations and comparison of pollutant release and transfer registers in the United States,

Canada, England, and Australia. *Risk Analysis* 27(1), 203-223. DOI: 10.1111/j.1539-6924.2006.00870.x.
Kessler, R. (2013). Sunset for leaded aviation gasoline? *Environmental Health Perspectives* 121(2), a54-a57. https://doi.org/10.1289/ehp.121-a54.
Krupp, E.M., Merle, J.K., Haas, K., Foote, G., Maubec, N., Feldmann, J.R. (2010) Volatilization of organotin species from municipal waste deposits: novel species identification and modeling of atmospheric stability. Environ Sci Technol 45(3):943–950. doi:10.1021/es102512u
Krupp, E. M., Merle, J. K., Haas, K., Foote, G., Maubec, N. and Feldmann, J. (2011). Volatilization of organotin species from municipal waste deposits: novel species identification and modeling of atmospheric stability. *Environmental Science & Technology* 45(3), 943-950. https://doi.org/10.1021/es102512u.
Lamas, G.A., Bhatnagar, A., Jones, M.R., Mann, K.K., Nasir, K., Tellez-Plaza, M., Ujueta, F., Navas-Acien, A.; American Heart Association Council on Epidemiology and Prevention; Council on Cardiovascular and Stroke Nursing; Council on Lifestyle and Cardiometabolic Health; Council on Peripheral Vascular Disease; and Council on the Kidney in Cardiovascular Disease (2023). Contaminant Metals as Cardiovascular Risk Factors: A Scientific Statement From the American Heart Association. J Am Heart Assoc. 2023 Jul 4;12(13):e029852. doi: 10.1161/JAHA.123.029852. Epub 2023 Jun 12. PMID: 37306302; PMCID: PMC10356104.
Larsen, B., Sánchez-Triana, E. (2023). Global health burden and cost of lead exposure in children and adults: a health impact and economic modelling analysis. *The Lancet Planetary Health* 7(10), e831 - e840. https://doi.org/10.1016/S2542-5196(23)00166-3.
Lee, S., Min, J.Y., Min, K.B. (2020). Female infertility associated with blood lead and cadmium levels. Int. J. Environ. Res. Public Health, 17 (5) (2020), 10.3390/IJERPH17051794.
Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H. et al. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet* 380(9859), 2224-2260. https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(12)61766-8.pdf.
Liu, X., Gao, W., Wie, T., Dong, Z., Ren, J., Shao, Y., Chen, X. (2024). Distribution and source of heavy metals in Tibetan Plateau topsoil: New insights into the influence of long-range transported sources to the surrounding glaciers. *Environmental Pollution* 346, 123498. DOI: 10.1016/j.envpol.2024.123498.
Liu, Q. (2025). Sources and control strategies of arsenic in the atmosphere. *Journal of Environmental & Earth Sciences, 7*(7), 209–226. https://doi.org/10.30564/jees.v7i7.9955.
Ma, R., Wang, H., Sun, Z., & Gu, X. (2025). Release and Ecological Risks of Heavy Metals During Coal Combustion in Coal-Fired Power Plants. *Applied Sciences*, *15*(21), 11360. https://doi.org/10.3390/app152111360.
Mahfooz, Y., Yasar, A., Guijian, L., Islam, Q. U., Akhtar, A. B. T., Rasheed, R. (2020). Critical risk analysis of metals toxicity in wastewater-irrigated soil and crops: a study of a semi-arid developing region. *Scientific Reports*, 10, 12845. DOI: 10.1038/s41598-020-69815-0.
Manoharan, E., & others. (2021). A Review of Hazardous Compounds Present in Construction and Demolition Waste (C&DW) and Their Environmental Effects. *Environmental Engineering Research*, 26(3), 340–354. DOI: 10.4491/eer.2021.14024514.
Masseck, T., París-Viviana, O., Habibi, S., et al. (2024). Integrated sustainability assessment of construction waste-based shading devices for the refurbishment of obsolete educational public building stock. *J Build Eng* 2024; 87: 109024.
Masten, S. J., Davies, S. H., Mcelmurry, S. P. (2017). Flint water crisis: what happened and why? *J Am Water Works Assoc.* 108(12), 22-34. DOI: 10.5942/jawwa.2016.108.0195.
Mathews, J. C., da Costa Assunção, F. P., Pereira, D. O., da Silva, J. C. C., Almeida, F. F. S., Almeida, A. C. P., Mendonça, N. M., de Sousa Brandão, I. W., Menezes, A. O., Borges, L. E. P., Ferreira, J. F. H., Pereira, J. A. R., & Machado, N. T. (2024). Metal Analysis of Leachate from the Organic Fraction of Urban Solid Waste (MSW) from the Municipality of Belém/PA. *Sustainability*, *16*(19), 8370. https://doi.org/10.3390/su16198370
Matschullat, J. (2000). Arsenic in the geosphere--a review. Science of the Total Environment 249(1-3), 297–312. doi:10.1016/s0048-9697(99)00524-0.

Molla, A. S., Tang, P., Sher, W., & Bekele, D. N. (2021). Chemicals of concern in construction and demolition waste fine residues: A systematic literature review. *Journal of environmental management*, *299*, 113654. https://doi.org/10.1016/j.jenvman.2021.113654.
Molla, A. S., Tang, W., Sher, W., Bahar, M. M., & Bekele, D. N. (2025). The Effects of Construction and Demolition Waste (C&DW) Fine Residues on Landfill Environments: A Column Leaching Experiment. *Toxics*, *13*(5), 370. https://doi.org/10.3390/toxics13050370.
Naz, S., Fazio, F., Habib, S. S., Nawaz, G., Attaullah, S., Ullah, M., Hayat, A., & Ahmed, I. (2022). Incidence of Heavy Metals in the Application of Fertilizers to Crops (Wheat and Rice), a Fish (Common carp) Pond and a Human Health Risk Assessment. *Sustainability*, *14*(20), 13441. https://doi.org/10.3390/su142013441.
Nguyen, T. T. T., et al. (2024). *Insight into heavy metal chemical fractions in ash collected from municipal solid waste incinerators. RSC Advances, 14*, d4ra01465k. https://doi.org/10.1039/d4ra01465k
Nriagu, J. and Pacyna, J. (1988). Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333, 134–139. https://doi.org/10.1038/333134a0
Nunes, L. M., Li, G., Chen, W.-Q., Meharg, A. A., O'Connor, P., Zhu, Y.-G. (2022). Embedded health risk from arsenic in globally traded rice. *Environmental Science & Technology* 56(10), 6415-6425. DOI: 10.1021/acs.est.1c08238.
Oberoi, S., Barchowsky, A., Wu, F. (2014). The global burden of disease for skin, lung, and bladder cancer caused by arsenic in food. *Cancer Epidemiol Biomarkers Prev* 23(7):1187-94. DOI: 10.1158/1055-9965.EPI-13-1317.
OECD-Organisation for Economic Co-operation and Development (2023). Raw Materials Critical for the Green Transition: Production, International Trade and Export Restrictions (Trade Policy Paper No. 269) (2023).
Peeters, K., Zuliani, T., Ščančar, J., & Milačič, R. (2014). The use of isotopically enriched tin tracers to follow the transformation of organotin compounds in landfill leachate. *Water research*, *53*, 297–309. https://doi.org/10.1016/j.watres.2014.01.034.
Qi, M., Wu, Y., Zhang, S., Li, G., & An, T. (2023). Pollution Profiles, Source Identification and Health Risk Assessment of Heavy Metals in Soil near a Non-Ferrous Metal Smelting Plant. *International Journal of Environmental Research and Public Health*, *20*(2), 1004. https://doi.org/10.3390/ijerph20021004.
Quevauviller, P., Donard, O.F.X., Bruchet, A. (1991). Leaching of organotin compounds from poly(vinyl chloride) (PVC) material. Appl Organomet Chem 5(2):125–129. doi:10.1002/aoc.590050210.
Rana, S.V (2014). Perspectives in endocrine toxicity of heavy metals--a review. Biol Trace Elem Res. 2014 Jul;160(1):1-14. doi: 10.1007/s12011-014-0023-7. Epub 2014 Jun 6. PMID: 24898714.
Rantakokko, P., Kuningas, T., Saastamoinen, K., Vartiainen, T. (2006). Dietary intake of organotin compounds in Finland: a market-basket study. Food Addit Contam 23(8):749–756. doi:10.1080/02652030600779908
Rashid, A., Schutte, B. J., Ulery, A., Deyholos, M. K., Sanogo, S., Lehnhoff, E. A., & Beck, L. (2023). Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health. *Agronomy*, *13*(6), 1521. https://doi.org/10.3390/agronomy13061521
Rasin, P., V, A. A., Basheer, S. M., Haribabu, J., Santibanez, J. F., Garrote, C. A., Arulraj, A., Mangalaraja, R. V. (2025). Exposure to cadmium and ist impacts on human health: a short review. *Journal of Hazardous Materials Advances* 17, 100608, DOI: 10.1016/j.hazadv.2025.100608.
Rosas-Castor, J. M., Guzmán-Mar, J. L., Hernández-Ramírez, A., Garza-González, M. T., Hinojosa-Reyes, L. (2014). Arsenic accumulation in maize crop (Zea mays): a review. *Science of the Total Environment*, 488-489, 176-187. DOI: 10.1016/j.scitotenv.2014.04.075.
RPA (2005). Risk assessment studies on targeted consumer applications of certain organotin compounds. https://ec.europa.eu/docsroom/documents/13041/attachments/1/translations/en/renditions/native
Sabir, S., Akash, M.S.H, Fiayyaz, F., Saleem, U., Mehmood, M,H., Rehman, K. (2019). Role of cadmium and arsenic as endocrine disruptors in the metabolism of carbohydrates: Inserting

the association into perspectives. Biomed Pharmacother. 2019 Jun;114:108802. doi: 10.1016/j.biopha.2019.108802. Epub 2019 Mar 25. PMID: 30921704.
Sadiki, A.I., Williams, D.T., Carrier, R., Thomas, B. (1996). Pilot study on the contamination of drinking water by organotin compounds from PVC materials. *Chemosphere*, 1996; **32**: 2389–2398.
Sadiki, A.I., Williams, D.T. (1999). A study on organotin levels in Canadian drinking water distributed through PVC pipes. *Chemosphere*, 1999; **38**: 1541–1548.
Santos, M.M., Enes, P., Reis-Henriques, M.A., Kuballa, J., Castro, L.F.C., Vieira, M.N. (2009). Organotin levels in seafood from Portuguese markets and the risk for consumers. Chemosphere 75:661–666. doi:10.1016/j.chemosphere.2008.12.066
Sawlani, N. (2023). Polyvinyl chloride market size to reach US$ 100.9 Bn by end of 2031, according to a TMR study. *Transparency Market Research Inc* 2023, Available at: https://www.digitaljournal.com/pr/news/polyvinyl-chloride-market-size-to-reach-us-100-9-bn-by-end-of-2031-according-to-a-tmr-study
Seewoo, B.J., Wong, E.V.S., Mulders, Y.R., et al (2024). Impacts associated with the plastic polymers polycarbonate, polystyrene, polyvinyl chloride, and polybutadiene across their life cycle: a review. *Heliyon* 2024; 10(12): e32912.
Shao, S., Tang, Y., Wang, C., Liu, X., Wang, C., & Wang, W. (2025). Contamination of heavy metal(loid)s in groundwater around mining and smelting area: quantitative source-oriented health risk assessment. *Environmental geochemistry and health*, *47*(8), 308. https://doi.org/10.1007/s10653-025-02625-3.
Singh, P., Mitra, P., Goyal, T., Sharma, S., & Sharma, P. (2021). Blood lead and cadmium levels in occupationally exposed workers and their effect on markers of DNA damage and repair. *Environmental Geochemistry and Health, 43*(1), 185–193. https://doi.org/10.1007/s10653-020-00696-y.
Shu, S.-N., Jiang, R.-T., Yin, J., Wang, Q., Su, L., Craig, N. J., Li, J.-Y. (2023). Characteristics, sources and health risks of organotin compounds in marine organisms from the seas adjacent tot he eastern ports of China. *Regional Studies in Marine Science* 61, 102929. DOI: 10.1016/j.rsma.2023.102929.
Sousa, A. C. A., Takahashi, S., Tanabe, S., Barroso, C. M. (2018). *Organotins: Ubiquitous presence in consumer products and human exposure.* In *Encyclopedia of the Anthropocene* (preprint). University of Évora. https://dspace.uevora.pt/rdpc/bitstream/10174/27625/1/SOusa%20et%20al.%20EncyclopediaAntropocene_preprint.pdf
Sousa, A.C.A., Patorinho, M.R., Takahashi, S. and Tanabe, S. (2014). History on organotin compounds, from snails to humans. Environmental Chemistry Letters 12, 117-137. https://doi.org/10.1007/s10311-013-0449-8.
Sripada, K., Lager, A. M. (2022). Interventions to reduce cadmium exposure in low- and middle-income countries during pregnancy and childhood: A systematic review. *Journal of Global Health*, 12, 04089. DOI: 10.7189/jogh.12.04089.
Su, K., Zhang, Q., Chen, A., et al. (2025). Heavy metals concentrations in commercial organic fertilizers and the potential risk of fertilization into soils. *Scientific Reports*, 15, 1230. DOI: 10.1038/s41598-024-79681-9.
Suwazono, Y., Kido, T., Nakagawa, H., Nishijo, M., Honda, R., Kobayashi, E., Dochi, M., Nogawa, K. (2009). *Biomarkers* 14(2), 77-81 DOI: 10.1080/13547500902730698.
Tian, H.Z., Zhu, C., Gao, J., Cheng, K., Hao, J., Wang, Kun, Hua, S., Wang, Yun, Zhou, J.(2015). Quantitative assessment of atmospheric emissions of toxic heavy metals from anthropogenic sources in China: Historical trend, spatial distribution, uncertainties, and control policies. Atmospheric Chemistry and Physics Discussions. 15. 12107-12166. 10.5194/acpd-15-12107-2015.
Turner, A., & Filella, M. (2021). Hazardous metal additives in plastics and their environmental impacts. *Environment international*, *156*, 106622. https://doi.org/10.1016/j.envint.2021.106622

UNEP (2010a). Final review of scientific information on lead. Geneva: UNEP Chemicals Branch. https://www.cms.int/sites/default/files/document/UNEP_GC26_INF_11_Add_1_Final_UNEP_Lead_review_and_apppendix_Dec_2010.pdf.
UNEP (2010b). Final review of scientific information on cadmium. Chemicals Branch, DTIE. http://wedocs.unep.org/xmlui/handle/20.500.11822/27636.
UNEP (2020a). Assessment of Informal Used Lead Acid Battery Recycling and Associated Impacts. 2020. https://www.unep.org/resources/assessment/assessment-informal-used-lead-acid-battery-recycling-and-associated-impacts.
UNEP (2020b). An assessment report on issues of concern: chemicals and waste issues posing risks to human health and the environment. https://wedocs.unep.org/handle/20.500.11822/33807
UNEP (2022a). Global Environment Facility (GEF) Project 9771: Global Best Practices on Emerging Chemicals Policy Issues of Concern under the Strategic Approach to International Chemicals Management. Lead Paint Reformulation Technical Guidelines. https://www.unep.org/resources/toolkits-manuals-and-guides/lead-paint-reformulation-technical-guidelines
UNEP (2022b). Assessment Report on Issues of Concern Factsheets: Arsenic. https://www.unep.org/resources/factsheet/assessment-report-issues-concern-factsheets.
UNEP (2022c). Assessment Report on Issues of Concern Factsheets: Cadmium. https://www.unep.org/resources/factsheet/assessment-report-issues-concern-factsheets.
UNEP (2022d). Assessment Report on Issues of Concern Factsheets: Lead. https://www.unep.org/resources/factsheet/assessment-report-issues-concern-factsheets.
UNEP (2022e). Assessment Report on Issues of Concern Factsheets: Organotins. https://www.unep.org/resources/factsheet/assessment-report-issues-concern-factsheets.
USGS (2025a). Lead Statistics and Information. Available at https://www.usgs.gov/centers/national-minerals-information-center/lead-statistics-and-information
USGS (2025b). Cadmium Statistics and Information. https://www.usgs.gov/centers/national-minerals-information-center/cadmium-statistics-and-information
USGS (2025c). Arsenic Statistics and Information. https://www.usgs.gov/centers/national-minerals-information-center/arsenic-statistics-and-information
Wai, K. M., Wu, S., Li, X., Jaffe, D. A. and Perry, K. D. (2016). Global atmospheric transport and source-receptor relationships for arsenic. Environmental Science & Technology 50(7), 3714-3720. https://pubs.acs.org/doi/10.1021/acs.est.5b05549.
Verified Market Research (2024). Polyvinyl chloride (PVC) market size and forecast. https://www.verifiedmarketresearch.com/product/polyvinyl-chloride-pvc-market/
Wang, M., Li, S. T. (2014). Heavy metals in fertilizers and effect of the fertilization on heavy metal accumulation in soils and crops. *Journal of Plant Nutrition and Fertilizers*, 20(2), 466-480. DOI: 10.11674/zwyf.2014.0224.
Wang, J., & Qiao, Z. (2024). A comprehensive review of landfill leachate treatment technologies. *Frontiers in Environmental Science, 12*, Article 1439128. https://doi.org/10.3389/fenvs.2024.1439128.
WHO (1999). Concise International Chemical Assessment Document 14: Tributyltin Oxide. Geneva: World Health Organization. https://www.who.int/ipcs/publications/cicad/en/cicad14.pdf
WHO (2000). Air Quality Guidelines for Europe. (2nd ed.) Copenhagen: WHO Regional Publications, European Series, No. 91-288. http://www.euro.who.int/en/publications/abstracts/air-quality-guidelines-for-europe.
WHO (2001). Environmental Health Criteria 224: Arsenic and Arsenic Compounds. (2nd ed.). Geneva: World Health Organization, International Programme on Chemical Safety. 1-108. https://apps.who.int/iris/bitstream/handle/10665/42366/WHO_EHC_224.pdf.
WHO (2006). Concise International Chemical Assessment Document 73: Mono- and Disubstituted Methyltin, Butyltin, and Octyltin Compounds. First draft: Dobson, S., Howe, P. D., Floyd, P. Geneva: UNEP, ILO, WHO, IOP for the Sound Management of Chemicals. https://apps.who.int/iris/bitstream/handle/10665/43549/9241530731_eng.pdf
Wiesinger, H., Bleuler, C., Christen, V., Favreau, P., Hellweg, S., Langer, M., Pasquettaz, R., Schönborn, A., Wang, Z. (2024). Legacy and emerging plasticizers and stabilizers in PVC

floorings and implications for recycling. *Environmental Science & Technology* 58(4), 1894-1907. DOI: 10.1021/acs.est.3c04851.

Yang, Q., Liu, G., Falandysz, J., Yang, L., Zhao, C., Chen, C., Sun, Y., Zheng, M., Jiang, G. (2024). Atmospheric emissions of particulate matter-bound heavy metals from industrial sources. *Science of the Total Environment*, 947, 174467. DOI: 10.1016/j.scitotenv.2024.174467.

Yi, A.X., Leung, K.M.Y., Lam, M.H.W, Lee, J-S, Giesy, J.P. (2012). Review of measured concentrations of triphenyltin compounds in marine ecosystems and meta-analysis of their risks to humans and the environment. Chemosphere 89(9):1015–1025. doi:10.1016/j.chemosphere.2012.05.080.

Zeng, X., Chen, Q., Tan, Q., Xu, H., Li, W., Yang, S., Wang, J., Ren, J., Luo, F., Tang, J., Wu, L., Zhang, Y., & Liu, D. (2021). Risk assessment of heavy metals in soils contaminated by smelting waste for the perspective of chemical fraction and spatial distribution. *Journal of Environmental Engineering and Landscape Management*, *29*(2), 101-110. https://doi.org/10.3846/jeelm.2021.14190.

Zhang, L., Gao, Y., Wu, S., Gao, H. (2020). Global impact of atmospheric arsenic on health risk: 2005 to 2015. *Proceedings of the National Academy of Sciences* 117(25), 13975-13982. DOI: 10.1073/pnas.2002580117.

Zou, H., Wang, T., Wang, Z-L., Wang, Z. (2023). Continuing large-scale global trade and illegal trade of highly hazardous chemicals. *Nature Sustainability* 6, 1394-1405. https://doi.org/10.1038/s41893-023-01158-w

24 Chemical Research. (2025). Global organotin stabilizers market research report 2025 (status and outlook) [Report No. 24CR-257423] (141 pp.).

Annex 1. A non-exhaustive compilation of major international decisions and resolutions explicitly referencing lead, cadmium, or heavy metals

UNEP, Report of the Governing Council on the work of its seventh session (A/34/25, 1979)
https://docs.un.org/en/A/34/25

Agenda 21, United Nations Conference on Environment & Development, 1992
https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf

UNEP, Report of the Governing Council on the work of its eighteenth session (A/50/25, 1995)
https://docs.un.org/en/A/50/25(SUPP)

S/19–2. Programme for the Further Implementation of Agenda 21 (A/RES/S-19/2; 1997)
https://docs.un.org/en/A/RES/S-19/2

UNEP, Report of the Governing Council, Twenty-first session (A/56/25; 2001)
https://docs.un.org/en/A/56/25(supp)

UNEP, Report of the Governing Council, Seventh special session (A/57/25, 2002)
https://docs.un.org/en/A/57/25(supp)

UNEP, Report of the Governing Council, Twenty-second session (A/58/25, 2003)
https://docs.un.org/en/A/58/25(supp)

UNEP, Report of the Governing Council, Twenty-third session (A/60/25, 2005)
https://docs.un.org/en/a/60/25(supp)

Fifth Session of the Intergovernmental Forum on Chemical Safety (IFCS/FORUM-V/05w, 2006)
https://cdn.who.int/media/docs/default-source/chemical-safety/ifcs/forum5/f5-final_report.pdf?sfvrsn=983b5edf_21&download=true

UNEP, Report of the Governing Council, Twenty-fourth session (A/62/25, 2007)
https://docs.un.org/en/A/62/25(SUPP)

UNEP, Report of the Governing Council, Twenty-fifth session (A/64/25, 2009)
https://docs.un.org/en/A/64/25(SUPP)

UNEP, Report of the Governing Council, Twenty-sixth session (A/66/25, 2011)
https://docs.un.org/en/A/66/25

UNEP, Report of the Governing Council/Global Ministerial Environment Forum (A/68/25, 2013)
https://docs.un.org/en/a/68/25

Proceedings of the United Nations Environment Assembly of the United Nations Environment Programme at its first session (UNEPA/EA.1/10, 2014)
https://docs.un.org/en/UNEP/EA.1/10

Proceedings of the United Nations Environment Assembly of the United Nations Environment Programme at its second session (UNEPA/EA.2/19, 2016)
https://docs.un.org/en/UNEP/EA.2/19

UNEA Resolution 3/9 Eliminating exposure to lead paint and promoting environmentally sound management of waste lead-acid batteries (UNEP/EA.3/Res.9, 2018)
https://docs.un.org/en/UNEP/EA.3/Res.9

UNEA Resolution 4/8 Sound management of chemicals and waste (UNEP/EA.4/Res.8, 2019)
https://docs.un.org/en/UNEP/EA.4/Res.8

UNEA Resolution 6/9 Sound management of chemicals and waste (UNEP/EA.6/Res.9, 2024)
https://docs.un.org/en/UNEP/EA.6/Res.9

WHA Resolution 78.27 Galvanizing global support for a lead-free future (2025)
https://apps.who.int/gb/ebwha/pdf_files/WHA78/A78_R27-en.pdf