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DELIVERING MULTIPLE BENEFITS THROUGH THE SOUND MANAGEMENT OF CHEMICALS AND WASTE

Delivering Multiple Benefits through the Sound Management of Chemicals and Waste

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Executive summary

The purpose of GEF's investments in chemicals and waste is to eliminate the use of the most harmful chemicals in accordance with a number of Multilateral Environmental Agreements (MEAs) which were established to protect human health and the environment, for example the Stockholm Convention on Persistent Organic Pollutants (POPs) and the Minamata Convention on Mercury.

Many projects have been designed to deal simply with a particular chemical, for example, cleaning up a waste dump or materials containing POPs. However, it is rare for these projects not to be related to other environmental and socio-economic issues, for example, cleaning up POPs is likely to have beneficial effects on land, soils, freshwater, and human health. Suitably designed, chemicals and waste projects can deliver multiple benefits: chemicals and waste global environmental benefits (GEBs), the primary purpose; other GEBs, e.g., biodiversity; local environmental benefits, e.g., improved air and water quality; and socio-economic benefits, e.g., jobs, food security, and human health.

Delivering these multiple benefits requires a systems thinking approach to develop a good understanding of the links between the various environmental elements, e.g., chemicals, air, land, and water, and with the societal elements, e.g., human health and well-being. Suitable indicators are also required to measure and monitor the environmental and socio-economic benefits.

This report examines the links between the GEF's goals for chemicals and waste, and those for its other focal areas, and their interactions with other environmental and socio-economic issues. It offers advice on how to design projects which recognize the various interlinkages and can deliver multiple environmental and socio-economic co-benefits, and it also makes recommendations on indicators.

In the near-term, as projects and programs are developed, the GEF should consider: applying systems thinking; develop a check list of environmental and socio-economic benefits; use qualitative, and where possible quantitative, indicators of co-benefits; allow flexibility in using indicators; and build capacity within the GEF partnership on systems thinking, mainstreaming co-benefits, and developing indicators to capture co-benefits, and encourage bringing in expertise in the social sciences and health.

Looking further ahead, the GEF could consider the following: strengthen the GEF indicators framework to include both GEBs, and environmental and socio-economic co-benefits; develop methodologies for assessing the direct and indirect environmental and socio-economic benefits of GEF investments; adopt qualitative analytical methods capturing benefits and monitoring and evaluation projects; develop or adopt composite indicators; and develop science-based targets for chemicals and waste.

1.0. Background

Chemicals are part of our daily lives. Almost all products involve chemicals. Properly used and managed, chemicals provide benefits that improve quality of life and human wellbeing, including in healthcare, energy, food and agriculture, and water and sanitation.

However, the improper use and disposal of chemicals pose significant threats to ecosystems and human health. The loss of biodiversity, water pollution, land degradation, and air pollution, are all linked to poor management of chemicals. The World Health Organization (WHO) estimated that using less chemicals, and their better management would have reduced the preventable disease burden in 2016 by about 1.6 million lives and 45 million disability-adjusted life years.[1]

The aim of the GEF's chemicals and waste focal area is to eliminate the use of the most harmful chemicals in accordance with the objectives of the Stockholm Convention on Persistent Organic Pollutants, the Minamata Convention on Mercury, and the Montreal Protocol on Substances that Deplete the Ozone Layer (only for countries with economies in transition). These Multilateral Environmental Agreements (MEAs) were established to protect human health and the environment. The GEF also supports some priorities of the Strategic Approach to International Chemicals Management (SAICM), a UN policy framework which promotes global chemical safety.

Traditionally, many chemicals and waste interventions were conceived of as dealing with a single issue, for example, cleaning up a chemical waste dump, but it is increasingly recognized that these interventions are interrelated with other environmental and socio-economic challenges; and that multiple benefits could be achieved, with synergies to be harnessed, and trade-offs to be managed.

More GEF chemicals and waste projects now recognize the importance of considering the interlinkages between chemicals and waste objectives and the GEF's biodiversity, climate change, land degradation, and international waters focal areas. Several multifocal area projects have been designed to exploit the interlinkages between focal areas to create solutions that can yield multiple global environmental benefits (GEBs). For example, some plastics projects eliminate persistent organic pollutants (POPs), and prevent marine and freshwater pollution. And managing the use of mercury in artisanal and small-scale gold mining (ASGM) can bring co-benefits in biodiversity, land degradation, and international waters.

The GEF-6 Integrated Approach Pilots and GEF-7 Impact Programs embody the notion that most environmental problems are intertwined with other complex economic, governance, and social concerns; and they recognize that problems should not be addressed in silos, but require a holistic approach for delivering multiple benefits and achieving transformational change.

Delivering multiple environmental and socio-economic benefits requires a good understanding of the interlinkages and complexities of the context within which a solution will be implemented. It also requires suitable indicators to estimate and monitor the environmental and socio-economic benefits arising from the intervention. This requires a systems thinking approach.

[1] WHO 2018.

This STAP advisory report discusses the interlinkages between the GEF's goals for chemicals and waste, and those of other focal areas, as well as the interactions with other environmental and socio-economic issues. The report, which is based on a detailed background document, [2] discusses the systems thinking approach and presents examples of its application in the production and use of chemicals, textiles, and electronics. Advice is offered on how to develop chemicals and waste projects that recognize interlinkages and deliver multiple environmental and socio-economic benefits.

2.0. Interlinkages between chemicals and waste and other environmental and socio-economic challenges

This section provides a scientific review of the interlinkages between the GEF's chemicals and waste objectives, and those of other focal areas, and discusses the socio-economic effects of chemicals and waste projects.

2.1. Stockholm Convention

The Stockholm Convention aims "to protect human health and the environment from persistent organic pollutants (POPs)."[3] POPs include organochlorine pesticides used in agriculture, as disinfectants, and in vector and disease control, [4] and industrial chemicals used in products such as electric transformers, heat exchange fluids, additives in paints, flame retardants, wood preservatives, non-stick kitchenware, inks, carpets, plastics, and electronics.[5] POPs are also unintentionally produced (uPOPs) as by-products from industrial processes, e.g., ferrous and non-ferrous metal production, brick production, pigment/painting industry, and coal-fired electricity, from controlled combustion or open burning of municipal, hazardous, and medical waste, as well as from automobile emissions and chemical reactions.[6]

Figure 2.1 presents a conceptual model of the effects of POPs on the environment and human beings. Pesticide and industrial POPs bioaccumulate in flora and fauna affecting terrestrial and aquatic biodiversity.[7] POPs also affect the growth and reproduction of microflora, such as bacteria and algae in soils and aquatic habitats, [8] and soil organisms such as earthworms and pot worms.[9] DDT, for example, inhibits cyanobacteria, which provides essential nitrogen-fixing and photosynthetic ecosystem services for plant growth. Sub-acute, acute, and lethal toxicity of POPs have been observed in aquatic invertebrates and warm-blooded animals, where organochlorine pesticides have been applied, leading to severe impairment of the diversity and structure of aquatic communities. [10] High concentrations of organochlorine pesticides have been found at the Keoladeo National Park in India, an important wintering site for migratory birds, including the critically endangered Siberian crane and two threatened eagle species.[11]

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[2] Hudelson et al., 2020

[3] http://www.pops.int/TheConvention/Overview/tabid/3351/Default.aspx

[4] Pesticides POPs: aldrin, chlordane, chlordecone, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), gamma-hexachlorocyclohexane, and byproducts of lindane (alpha-hexachlorocyclohexane, beta-hexachlorocyclohexane mirex, & toxaphene.

[5] Industrial POPs: tetra and pentabromodiphenyl ethers (PBDEs), hexa and heptabromodiphenyl ethers, hexabromobiphenyl, perfluorooctane sulfonic acid (PFOs), its salts and perfluorooctane sulfonyl fluoride (PFOs-F), pentachlorobenzene (PeCB), and polychlorinated biphenyls (PCBs).

[6] Unintentional POPs: HCB, PeCB, PCBs, polychlorinated dibenzo-p-dioxins (PCDDs or dioxins) and dibenzofurans (PCDFs or furans).

[7] Aktar et al., 2009; Corsolini & Sarà, 2017; Taiwo, 2019; Vallack et al., 1998

[8] DeLorenzo et al., 2001; Megharaj et al., 2000.

[9] Liang et al., 2018; Römbke et al., 2017; Shi et al., 2018.

[10] Welch & Spindler, 1964; Beketov et al., 2013; Leonard et al., 2000

[11] Bhadouria et al., 2012; UNESCO, 2020

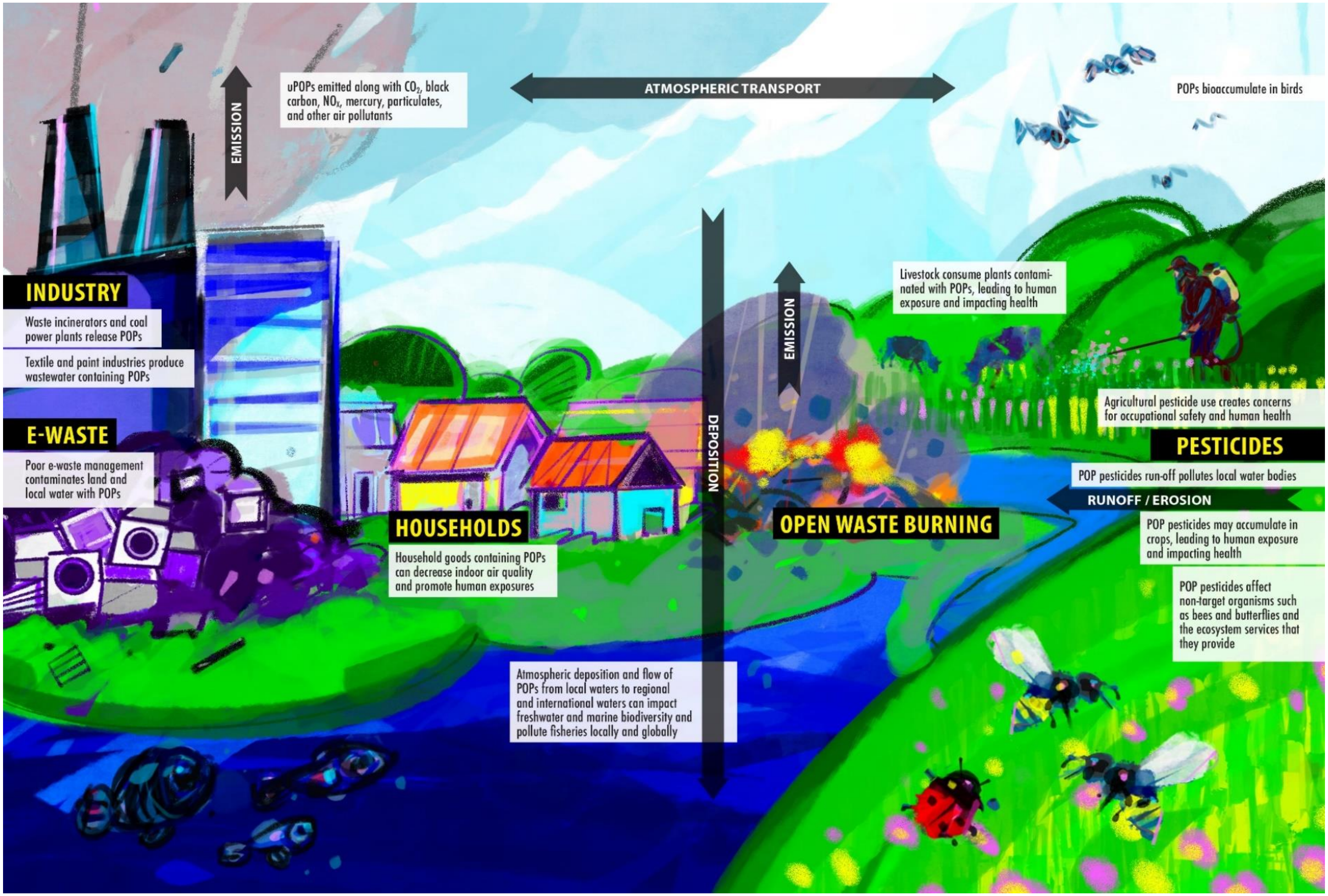

Figure 2.1. Conceptual model highlighting the interlinkages between POPs and other environmental (including GEF focal areas) and socio-economic issues

Pesticide and industrial POPs contaminate soils and promote land degradation. DDT residues have been reported in agricultural areas of all the 23 countries of the Wider Caribbean Region.[12] A substantial proportion of applied pesticides enters local surface and groundwater resources and the marine environment, including international waters, through drainage, runoff, erosion, misapplication, and atmospheric transport.[13] PFOS, PBDEs, PCBs, and PFOA have been detected globally in the oceans caused by atmospheric transport and transboundary deposition. POPs such as PCBs threaten orca whales, dolphins, seals, polar bears, and many other species.[14] High levels of PCBs and PBDEs were found in fish from coastal waters in South China close to an e-waste recycling site, along with evidence of biomagnification in the aquatic food web.[15] Studies have also shown that water birds, chicken, ducks, mice, and frogs have also been exposed to PBDEs from e-waste sites.[16] Poor end-of-life management of electrical and electronic products containing POPs has also been linked to land degradation.[17]

The atmospheric transport and deposition of uPOPs leads to loss of biodiversity and ecosystem services, such as the regulation of air, soil, freshwater and groundwater quality, pollination by insects, and contaminates food sources from terrestrial and aquatic habitats, with implications for human health. Globally, it is estimated that 40 percent of the dioxins and furans generated annually enter into the oceans through atmospheric transport.[18] These toxic uPOPs have been detected in aquatic organisms at all levels in the world's oceans, including phytoplankton, fish, seabirds, turtles, otters, seals, sharks, and whales; and are known to cause adverse effects, including endocrine disruption, developmental and reproductive effects, and immunotoxicity in biota.[19] Dioxins and furans from the open burning of waste contaminate nearby soils and local freshwater resources due to atmospheric transport and deposition. High levels of concentration have been reported in soil from municipal dumpsites[20] and in sediments of freshwater systems[21] near the open burning of waste.

Apart from effects on biodiversity, water, and land, open burning of waste and other sources of uPOPs, such as ferrous and non-ferrous metal production, brick production, and coal-fired plants, emit greenhouse gases and air pollutants, including carbon dioxide (CO_2), methane, nitrous oxide, particulates, carbon monoxide, and black carbon. Measures to mitigate climate change and air pollution will help to reduce emissions of uPOPs, for example, through better waste management strategies, improved exhaust air filtering, replacing coal as a fuel source, and cleaner and environmentally friendly manufacturing processes. These emissions may also contain mercury (see section 2.2) – so the abatement of greenhouse gases, air pollutants, and mercury may be achieved synergistically.

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[12] Fernandez et al., 2007.
[13] UNEP 1994.
[14] Desforges et al., 2018; Jepson & Law, 2016; Schnitzler et al., 2019
[15] Zhang et al., 2010
[16] Zhang et al., 2011; Zhao et al., 2016
[17] Brigden et al., 2008; Lundgren, 2012; Petrlik et al., 2019.
[18] Booth et al., 2013
[19] Alaee 2016; Dorneles et al., 2013; Kumar et al., 2001
[20] Brigden et al., 2008; DiGangi & Petrlik, 2005; Minh et al., 2003; Petrlik et al., 2019; Zhang et al., 2011
[21] Brigden et al., 2008; Petrlik et al., 2019; Ssebugere et al., 2013

2.2. Minamata Convention

The Minamata Convention aims "to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds." [22] Sources of mercury include ASGM, batteries, electrical and electronic products, cosmetics, measuring devices, pesticides, and dental amalgam. Other sources include manufacturing processes such as Chlor-alkali production[23] and point emission sources, such as coal-fired power plants and industrial boilers, cement production, waste incineration, and non-ferrous metals production.

Figure 2.2 highlights the interlinkages between mercury and the environment, and human health. The clearing of vegetation for ASGM contributes to deforestation, which affects biodiversity, climate change, land degradation, and water pollution. Mercury-based ASGM has been documented in biodiversity hotspots and protected areas,[24] and has contaminated croplands and caused soil erosion.[25] ASGM affects local and international waters through the direct release of mercury, for example, in Lake Victoria[26] and Amazon River,[27] and through atmospheric deposition in waterways.[28] This affects fisheries and other natural resources. Mercury affects ecosystem services such as nature's ability to regulate air and water quality and pollutes foods grown in soil or harvested from fresh and marine environments.[29]

The end-of-life management of products containing mercury can lead to air, land, and water pollution, e.g., through open burning, incineration, landfilling, and treatment along with sewage sludge. The use of sewage sludge or wastewater containing mercury on agricultural land is a source of soil contamination; this may facilitate the emission of mercury into the atmosphere, pollute rivers and groundwater, and affect soil microorganisms and crop quality.[30] Similarly, wastewater from Chlor-alkali facilities has led to the contamination of nearby freshwaters.[31]

Coal-burning facilities have been linked to mercury contamination of nearby air and land. The atmospheric transport of mercury leads to deposition into distant soils, rivers, lake sediments, and international waters.[32] Furthermore, waste from coal-fired plants is a source of air and water pollution, and coal ash tailings cause mercury methylation,[33] which enhances the toxicity of mercury.[34]

[22] http://www.mercuryconvention.org/Portals/11/documents/Booklets/COP3-version/Minamata-Convention-booklet-Sep2019-EN.pdf
[23] The production of chlorine and sodium hydroxide in which mercury is used as part of the process.
[24] For example, Palacios-Torres et al., 2018; Asner et al., 2013; Dethier et al., 2019; Edwards et al., 2014 ; Kawakami, 2019; Papworth et al., 2017
[25] Esdaile & Chalker, 2018; Diringer et al., 2015
[26] Campbell et al., 2003
[27] Asner & Tupayachi, 2016
[28] UNEP 2019
[29] Driscoll et al., 2013
[30] Carpi et al., 1997; Wu et al., 2010.
[31] Bravo et al., 2010
[32] Lindberg & Stratton, 1998; Schroeder & Munthe, 1998; Liu et al., 2018; Razi & Hiroshi, 2012; Martín & Nanos, 2016; Sanei et al., 2010.
[33] Methylation is the process whereby mercury is transformed to the more toxic methylmercury.
[34] Hendryx et al., 2020; Kravchenko & Lyerly, 2018; Schwartz et al., 2016

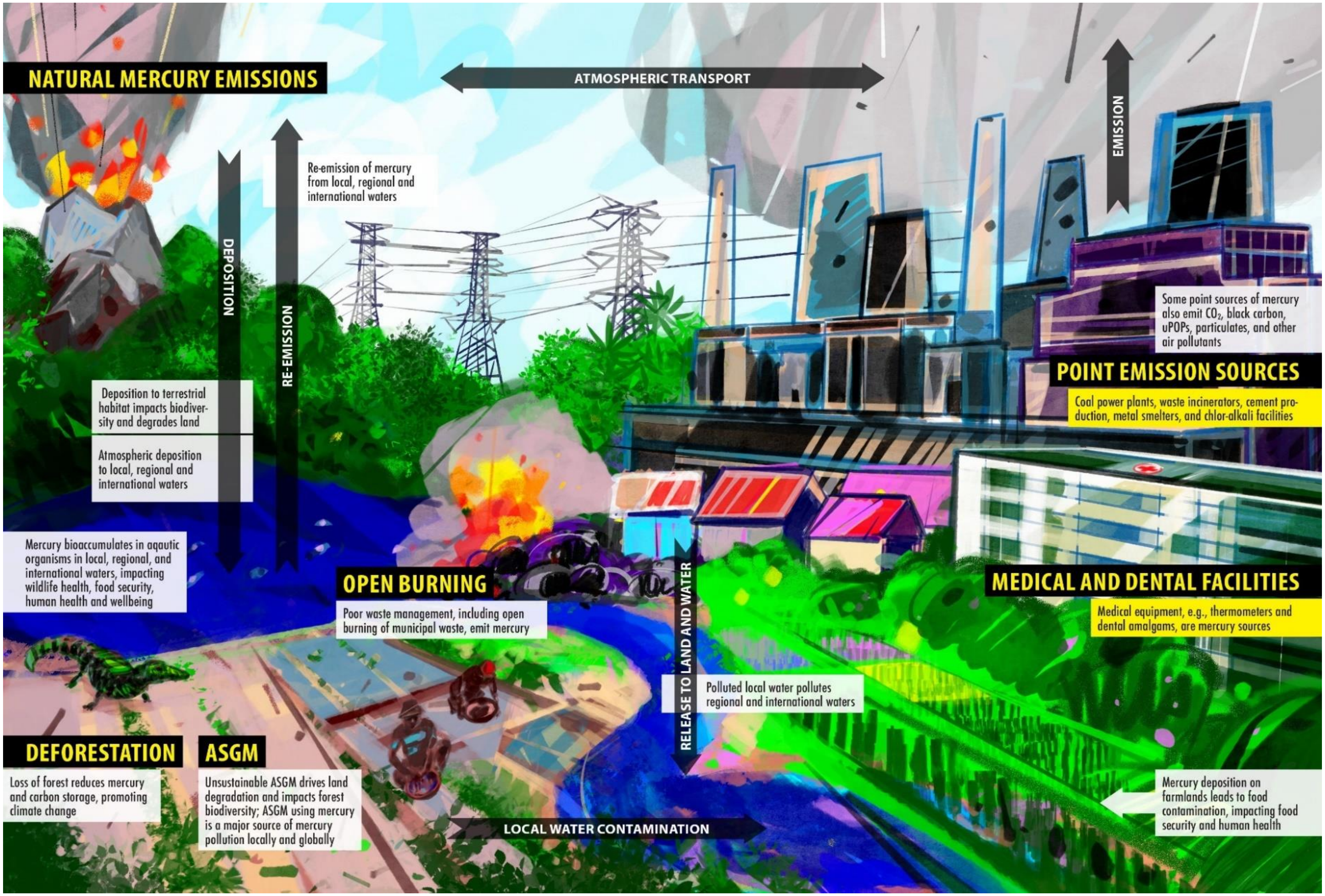

Figure 2.2. Conceptual model highlighting the interlinkages between mercury pollution and other environmental (including GEF focal areas) and socio-economic issues

Point sources of mercury emissions are significant emitters of greenhouse gases and air pollutants (e.g., sulfur dioxide, nitrogen oxides, and particulate matter), as well as uPOPs (dioxins and furans). The mitigation of climate change and air pollution can help to address mercury and uPOPs emissions, for example, through renewable alternatives to coal, better waste management, and end-of-pipe treatment of industrial exhaust. Similarly, promoting clean and energy-efficient industrial production can simultaneously achieve climate goals and reduce mercury release, for example, in the Chlor-alkali industry, where replacement plants are usually more energy-efficient. And replacing electrical equipment, for example, lamps, with alternatives that are mercury-free and energy-efficient, can also help to achieve climate change and mercury emission mitigation objectives.

2.3. Montreal Protocol

Emissions of Ozone Depleting Substances (ODS) significantly depletes and modifies the ozone layer and results in adverse effects on human health and the environment. The Montreal Protocol aims to protect the ozone layer by taking precautionary measures to control the global emissions of ODS,[35] from products such as refrigerators, air conditioners, fire extinguishers, foam blowing agents, industrial and cleaning solvents, aerosol spray propellants, and fumigants.

Figure 2.3 depicts the interlinkages between ODS and the environment. Apart from the significant success of closing the ozone hole achieved by the Montreal Protocol,[36] eliminating ODS provides significant climate change mitigation benefits. Implementing the Montreal Protocol is estimated to have mitigated 25 percent of global warming, which would have occurred by 2050, through the combined effects of protecting the ozone layer and mitigating potent greenhouse gas emissions.[37] The enforcement of the Kigali Amendment to the Montreal Protocol (in which countries committed to cut the production and consumption of HFCs by more than 80 percent over the next 30 years) is expected to avoid up to 0.5 ˚C of global warming by 2100.[38] Furthermore, combining the phasing out of hydrofluorocarbons (HFCs), a refrigerant in air conditioning, with energy efficiency reduces energy demand and provides climate mitigation benefits.[39]

High ultraviolet radiation levels can exacerbate coral reef bleaching in shallow waters, and UV radiation can trigger bleaching even in the absence of elevated water temperature under certain conditions.[40] Globally there are estimated to be 2,679 marine protected areas in coral reefs areas[41] which have high endemic biodiversity,[42] and the Montreal Protocol has reduced pressure on these sensitive and threatened ecosystems. Other aquatic organisms, such as zooplankton and sea urchins, are also susceptible to ultraviolet radiation, especially at their embryonic and early life stages.[43]

[35] https://ozone.unep.org/sites/default/files/Handbooks/MP-Handbook-2020-English.pdf
[36] Banerjee et al., 2020
[37] Goyal et al., 2019.
[38] Xu et al., 2013
[39] Shah et al., 2015.
[40] Gleason & Wellington, 1993
[41] WRI, 2011
[42] Connell, 1978
[43] Bancroft et al., 2007; Smith & Baker, 1989; Häder et al., 1991.

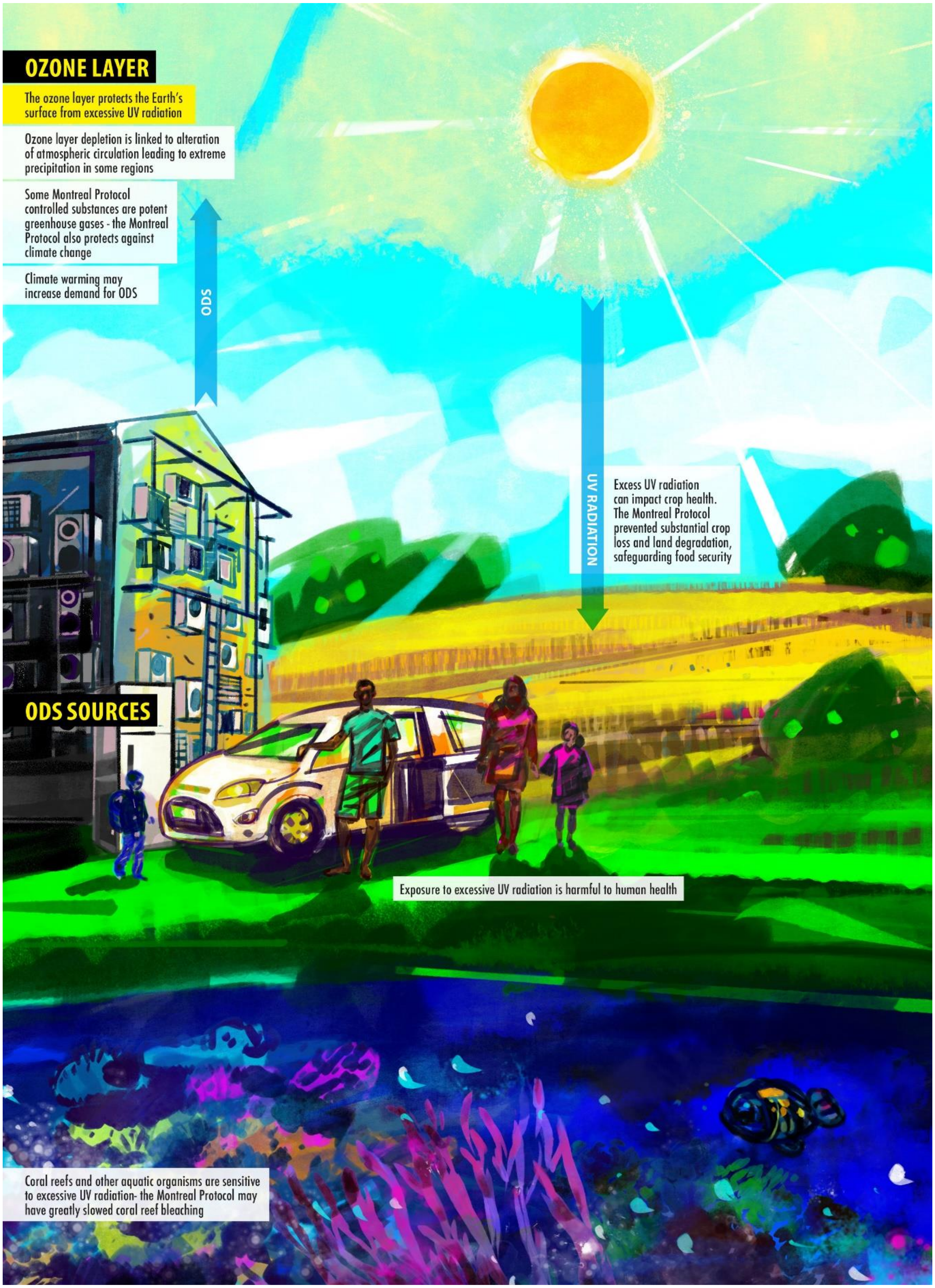

Figure 2.3. Conceptual model showing the interlinkages between ODS and other environmental (including GEF focal areas) and socio-economic issues

Depletion of the ozone layer has been linked to changes in atmospheric circulation, affecting rainfall patterns and ocean circulation, and also to an increased frequency of extreme precipitation events and drought.[44] Warmer summers in Southern Africa, between 1993 and 2010, have been linked to the hole in the ozone hole.[45] Ozone depletion has been linked to warmer summers at high latitudes leading to increased wildfire activity, affecting forests, biodiversity, and land.[46]

Hydrofluoroolefin (HFO-1234yf) was introduced as an ODS replacement but was found to degrade into short-chain fluorinated alkyl acids, which are highly mobile POPs.[47] This illustrates the link between the Montreal Protocol and the Stockholm convention.

2.4. Strategic Approach to International Chemicals Management (SAICM)

The overall goal of SAICM is to achieve the sound management of chemicals throughout their life cycle so that chemicals are produced and used in ways that minimize significant adverse impacts on the environment and human health.[48] SAICM has adopted resolutions on a number of emerging policy issues and other issues of concern. These include lead in paint, chemicals in products, hazardous substances within the life cycle of electrical and electronic products, nanotechnology and manufactured nanomaterials, and endocrine-disrupting chemicals. Others include environmentally persistent pharmaceutical pollutants, perfluorinated chemicals and transition to safer alternatives, and highly hazardous pesticides.

These emerging issues are linked to GEF focal areas. For example, lead is an additive in marine paints, and may lead to marine pollution and adversely affect marine biodiversity.[49] Plastic products can contain POPs and other hazardous chemicals. Poor management of plastics leads to marine litter and contamination of marine, coastal, and freshwater habitats with a significant effect on biodiversity. Plastic pollution is the second most significant threat to the future of coral reefs, after climate change.[50] Inadequate disposal of plastics leads to the contamination of lands and water resources by toxic chemicals and microplastics.[51] Discarded plastics, when exposed to sunlight, release methane – a very potent greenhouse gas.[52] Details of the impact of plastics on the GEF's focal areas can be found in STAP's report on plastics and the circular economy.[53]

Much e-waste contains POPs and other hazardous chemicals and exhibits the same interlinkages with POPs as discussed in section 2.1. Highly hazardous pesticides and perfluorinated chemicals are of similar concern as pesticides and industrial POPs, respectively, and the interlinkages in section 2.1 are also relevant, with effects on biodiversity, land, water, and air.

[44] Robinson & Erickson, 2015
[45] Manatsa et al., 2013
[46] Holz et al., 2017
[47] Pickard et al., 2020
[48] http://www.saicm.org/About/SAICMOverview/tabid/5522/language/en-GB/Default.aspx
[49] Espejo et al., 2019
[50] Lamb et al., 2018.
[51] Barra & Leonard, 2018.
[52] Royer et al., 2018.
[53] Barra & Leonard, 2018.

2.5. The effects of climate change on chemicals and waste

In addition to chemicals and waste affecting other GEF focal areas, a changing climate affects the use, emissions, environmental distribution, and the effects of chemicals on the environment. For example, climate change is expected to increase the incidence of agricultural pests and reduce agricultural productivity leading to an increased use of pesticides.[54] The potency of pesticides will reduce as they are expected to be broken down more readily in warmer and wetter conditions, thereby encourage increase application.[55] The 2019/20 plague of locusts in East Africa has been linked to climate change and has led to the increased use of pesticides,[56] which will increase greenhouse gas emissions from pesticide production.

Increased flooding events, drought-flood cycles, and extreme weather will lead to the remobilization of POPs in sediments, increasing its bioavailability to organisms.[57] Warming can cause POPs to more easily evaporate,[58] for example, from electrical equipment, joint sealants, paints, and plastics. A 1°C rise in temperature has been estimated to increase the volatility of some POPs (e.g., PCBs) by 10–15 percent, and a 10°C rise (which is possible at the local scale in the Arctic) could result in a 3-fold increase in volatility of POPs.[59] Climate change will lead to the increased release of POPs from melting ice and water no longer covered by sea ice.[60] Warming will cause volatile chemicals to disperse more quickly in the air. The global movement of persistent chemicals, including POPs, will be modified as air and water currents change, thereby affecting their distribution the global environment, and POPs will degrade more quickly in some areas.

With continued warming, mercury and methylmercury stored in Arctic soils, water, and ice may be remobilized and released into the environment[61], and the release of mercury from terrestrial sources (soils and shales) to the atmosphere is expected to increase with rising temperatures,[62] because the flow of mercury from terrestrial sources increases with air temperature.[63] Warming may also increase the bioaccumulation and fish toxicity of methylmercury in freshwater and marine environments.[64]

Climate change will lead to increased frequency and intensity of events such as flood-drought cycles. The fluctuation of water levels due to frequent changes in flood-drought cycles will affect mercury mobility and methylation in soils, sediments, and biota.[65] More forest fires caused by climate change will lead to the emission of mercury stored in plants.[66] Hurricanes may remobilize mercury stored in organic matter in coastal environments, leading to increased bioaccumulation and biomagnification in downstream food webs.[67]

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[54] Delcour et al., 2015.
[55] Matzrafi, 2019; Ziska, 2014
[56] Stone 2020.
[57] Bonnet et al., 2000; Guigue et al., 2017
[58] Schwarzenbach et al., 2003
[59] UNEP/AMAP 2011
[60] UNEP/AMAP 2011
[61] Schuster et al., 2018; St. Pierre et al., 2018; Fahnestock et al., 2019.
[62] MacSween et al., 2020
[63] Agnan et al., 2016; Almeida et al., 2009; Engle et al., 2001; Poissant et al., 1999
[64] Alava et al., 2018; Camacho et al., 2020; Evans et al., 2013
[65] Liu et al., 2020; Xiang et al., 2018; Sorensen et al., 2005
[66] Obrist et al., 2018
[67] Tsui et al., 2020

Extreme weather events may trigger catastrophic failures of enclosures of mercury-contaminated wastes such as coal ash.[68] Sea-level rise can inundate contaminated lands and waste management facilities (e.g., landfills, hazardous chemicals sites, and wastewater management infrastructure), leading to the remobilization of toxic chemicals, including POPs, mercury, and methylmercury, stored in historic landfills.[69] Climate change may affect the clean-up of released hazardous substances and the rehabilitation of contaminated land and associated natural resources. The toxicity of some hazardous materials increases with temperature, which may make restoration more costly. More frequent and intense extreme weather events might also slow down the rate of recovery of treated hazardous material from contaminated sites.[70]

2.6. Socioeconomic aspects of chemicals and waste

Chemicals and waste are linked to socio-economic conditions:

Health: The overarching objective of the chemical MEAs is to protect human health and the environment from harmful chemicals. POPs, mercury, ODS, and chemicals listed in the SAICM's emerging issues are all linked to adverse effects on human beings. The sound management of chemicals would yield significant health benefits.

Food Security: POPs and mercury affect the food web and the ecosystem services that support food production (e.g., pollination and soils), and food security, through the safety and availability of produced food. Plants and marine organisms, including fishes, are highly susceptible to UV radiation stress. Reducing the use of ODS would help prevent crop yield loss. In the absence of the Montreal Protocol, it is estimated that there would have been global economic losses of US$238 billion and US$191 billion from fisheries and agricultural damages, respectively, between 1987 and 2060.[71]

Economic benefits: Hazardous chemicals can cause ill-health and reduce people's ability to work. Harmful chemicals damage natural resources and impair livelihoods. The adverse health effects of chemicals increase the burden on healthcare and educational facilities. Chemical pollution leads to extra costs, for example, in cleaning up contaminated sites or the treatment of polluted waters. The sound management of chemicals through adopting a circular economy approach, or using cleaner technologies, could create new jobs and provide economic benefits to individuals and communities.

Poverty and gender equality: Women and children, especially the poor, are usually disproportionately exposed to the effects of chemicals, because their bodies are more susceptible to the effects of certain chemicals.[72] In some roles, such as planting and harvesting of crops, female workers are the majority of the workforce and likely to be exposed to chemicals. In other roles, such as pesticide application, men are more directly impacted.[73] Poor people tend to live closer to areas where pollution occurs, e.g., adjacent

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[68] Silverstein, 2018
[69] Historic landfills are known to be rich in mercury and methylmercury (Yang et al. 2018).
[70] Rohr et al., 2013.
[71] UNEP, 2012
[72] For example, Landrigan & Goldman, 2011; UNDP, 2011
[73] For example, UNDP, 2011

to industrial zones, have less access to modern and clean facilities, and may lack preventive knowledge. The sound management of chemicals would help to reduce these impacts and bridge the gender equality gap.

3.0 Designing chemicals and waste projects and capturing the co-benefits

The GEF's objectives on chemicals and waste are strongly interlinked with its objectives in other focal areas. The production, use, and management of persistent organic pollutants (POPs), mercury, ozone-depleting substances (ODS) are major drivers of biodiversity loss, climate change, land degradation, and affect international waters. Chemicals and waste also affect other environmental issues, including air pollution and the contamination of local water sources, and socio-economic issues and well-being, including human health, food security, poverty, gender equality, and economic development. The sound management of chemicals can deliver multiple benefits in all focal areas, as well as other environmental and provide socio-economic benefits.

To address interlinkages, deliver multiple benefits, and transformational change, chemicals and waste interventions should be designed with a number of important foundational "enabling" elements on which STAP has provided advice. These are described in Box 3.1.

Box 3.1: Key "enabling" elements in project and program design

- Apply systems thinking: [74] devise a logical sequence of interventions, which is responsive to changing circumstances. Address inter-connected environmental, social, economic, and governance challenges across sectors in design and implementation, with an eye towards resilience, transformational and enduring change.
- Develop a clear rationale and robust theory of change[75] to tackle the drivers of environmental degradation by assessing assumptions and outlining causal pathways, and by devising responses that are robust to future change and adaptive if desired outcomes do not materialize.
- Choose the innovations[76] to be scaled (including technological, financial, business model, policy, and institutional innovation).
- Allow flexibility in project preparation to accommodate the additional transaction costs and time required to tackle complex issues through multi-agency teams. [77]
- Assess climate risk[78] at the project development stage and develop ameliorative actions to ensure that project outcomes are achieved; and consider how co-benefits can be enhanced by adaptive actions.
- Analyze the barriers to, and enablers of, scaling and transformation, [79] for example, institutional, governance, cultural, and vested interests. Assess the potential risks, including climate risk, and vulnerabilities to the system, to measure resilience to shocks and changes, the need for incremental adaptation, or more fundamental transformational change.

[74] Bierbaum et al., 2018
[75] Stafford-Smith et al., 2019a
[76] Toth et al., 2018
[77] Stafford Smith et al., 2019b
[78] STAP, 2019.
[79] Stafford Smith et al., 2019b

- Maximize global environmental benefits, [80] by improving effective integration, and by identifying positive synergies among multiple benefits, and avoid doing harm, by minimizing negative interactions, and managing any trade-offs, including climate risk and other long-term changes.
- Develop multi-stakeholder dialogue[81] from inception and design, through to project completion, ideally building on existing platforms, and flexibly structured to extend and evolve over time towards enduring transformational change.
- Establish a monitoring, evaluation, and learning process [82] to track the intended innovations, integration and transformation, as well as indicators of durability. Develop explicit plans and funding for good quality knowledge management including sustainable databases, simple, useful and usable common indicators; this is essential for 'lessons learned' and scaling up.
- Ensure durability[83] in project outcomes and impacts by applying all of the above key elements and engaging the right stakeholders; building the incentives for these key actors to act; incorporating adequate flexibility in project design and implementation; and underpinning it all with a systems-thinking approach.

3.1 The systems approach to designing chemicals and waste projects

Systems thinking examines the relationships between the different parts of a system, for example, the product manufacturing system, and a chemical supply chain. It focuses especially on cause and effect relationships, and positive or negative feedback mechanisms, between the biophysical and socio-economic features of the system. It also considers the interactions between components of a system across different locations and organizational levels, as well as over time. Because many of these relationships are non-linear, understanding the connections between variables helps to identify points for effective intervention. [84]

Employing systems thinking involves conducting systems analysis[85] to understand systems components, interlinkages, synergies, and tradeoffs,[86] and deploying relevant tools or principles that target the drivers and root cause of problems and help change underlying systems goals and paradigms. Systems thinking also involves bringing together relevant systems stakeholders,[87] for example private sector actors and government institutions, who are essential to changing how the chemicals and waste system operates.

The three examples[88] below illustrate systems thinking in chemicals and waste: in the textiles and garment sector, in the production, sales, and use of chemicals, and in the electronics sector.

[80] Bierbaum et al., 2018.
[81] Ratner & Stafford Smith, 2020
[82] Stocking et al., 2018
[83] Stafford Smith et al., 2019b
[84] Bierbaum et al., 2018
[85] Systems analysis is the process of collecting and interpreting information about a system to identify systems components, objectives, and problems and create solutions.
[86] A review of selected past and ongoing GEF chemicals and waste projects and multi-focal area projects involving chemicals and waste indicates that a detailed analysis of interlinkages between targeted issues and other environmental and socioeconomic issues is often lacking.
[87] For more information on effective stakeholder engagement, see STAP report on multi-stakeholder dialogue (Ratner & Stafford Smith, 2020).
[88] More examples are available in the background paper to this report (Hudelson et al., 2020).

3.1.1. Promoting environmental sustainability in the textiles and garment sector[89]

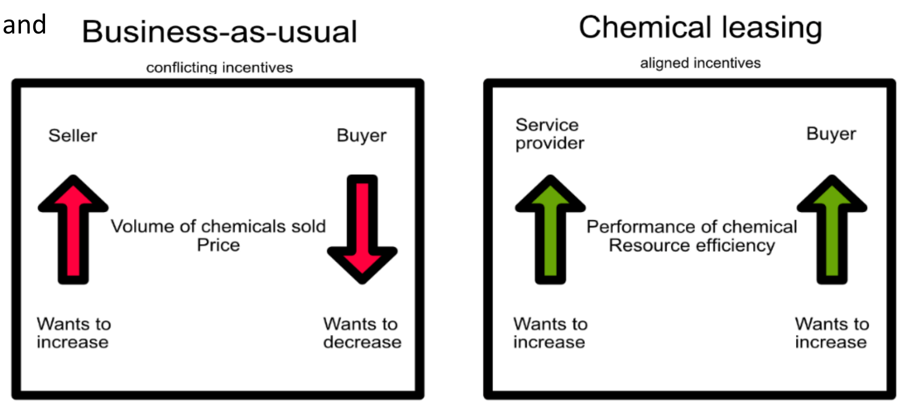
- The textiles industry is an important, fast-growing, but high-polluting sector, associated with substantial land, water, and energy use. More than 1,900 chemicals are used, with 165 classified as hazardous, including some POPs.
- Textiles are linked with air pollution, water pollution, greenhouse gas emissions, microplastics pollution, and waste management challenges, with very low reuse and recycling rates.
- Typical solutions are end-of-pipe waste or wastewater treatment or changing production processes to reduce chemical pollution.
- A systems thinking approach would consider all the system's elements, including farming practices, production and processing technologies, type of chemicals used, supply chains, prevailing legislation and policies, consumption patterns, commodity and consumer markets, societal idea of fashion, level f ecological literacy in the society, and vision of manufacturers and retailers.
- Based on the analysis of interactions between the systems elements, a systems thinking-based intervention could combine end-of-pipe solutions with regulations or incentives that encourage greater producer responsibility, embracing a "green chemistry"[90] solution for chemical production and use, or adoption of labeling or certification schemes to help consumers make more sustainable clothing choices.
- Deeper systems thinking interventions may aim to change the sector to one more focused on a circular economy approach. This may include deploying the: "slow fashion" concept, which encourages consumers to buy fewer clothes of better quality and durability; or "fashion or clothing as a service" model, in which clothes and accessories are not owned by customers but provided to them temporarily through subscription or rental; or "circular fashion" solutions, in which clothes and accessories are designed, sourced, produced, and used responsibly for as long as possible in their most valuable form and later return safely to the environment (e.g., by composting) at the end of life.
- Implementing these concepts would require the redesign of how textiles are made and adopting novel economic and business models, in which the goal of the sector is not only profit maximization but also promoting functionality, sustainability, as well as business and customer satisfaction.

[89] Based on Choudhury, 2014; Sajn, 2019; Toprak & Anis, 2017; KEMI, 2013; Roca & Herva, 2015; Fletcher, 2009; Nguyen et al., 2015

[90] Green chemistry seeks to ensure that the design, development and implementation of chemical products and processes protect and benefit the economy, people and the planet by finding creative and innovative ways to reduce waste, conserve energy, and discover replacements for hazardous substances. In green chemistry, the definition of performance of chemical products changes from functions alone to functions and sustainability (Zimmerman et al., 2020 and https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry.html).

3.1.2. Improving the sustainability of chemical production, sales, and use through green chemistry and chemical leasing [91]

- The production capacity of the global chemical industry almost doubled from 1.2 billion metric tons in 2000 to 2.3 billion metric tons in 2017 and the global size of the industry is projected to double by 2030 from the 2017 value of USD5.7 trillion under business as usual scenario.
- The production of several toxic chemicals, including those of concern to the chemical conventions and SAICM, is associated with increased energy and resource consumption, toxic wastes, biodiversity loss, water pollution, land degradation, as well as adverse effects on human health and welfare.
- Most chemicals management solutions focus on adjusting production processes to improve efficiency, deploying end-of-pipe treatment of wastes and by-products, or regulations to restrict production.
- The chemical leasing model is an alternative intervention to change the goal from maximizing sales volume to a performance-based paradigm that seeks to maximize the usefulness of chemicals. It is a service-oriented model that aligns the objective of chemical suppliers and buyers by selling the functions of chemicals, rather than focusing on the volume of sales - reducing environmental and health impacts, improving occupational safety, and ensuring long-term sustainability of the sector.
- The chemical leasing model encourages manufacturers to produce chemicals through green chemistry. This incorporates systems and design thinking to ensure that chemicals are benign and beneficial, produced from renewable feedstocks, employ circular manufacturing process, and are defined by both functionality and sustainability.



The business-as-usual vs chemical leasing model for chemical production and use (Source: adapted from UNIDO, 2016)

- The chemical leasing model has been successfully applied in electronic manufacture, metal fabrication, wastewater and drinking water treatment, the petrochemical industries, and agricultural pesticides, yielding environmental, health, occupational safety, and other socio-economic benefits.

3.1.3. Enhancing the sustainability of the electronics sector through the circular economy model [92]

- The current linear take-make-use-dispose model in the electronics sector has resulted in adverse environmental and human health impacts. The mining and processing of minerals used in electronics leads to greenhouse gas emissions, land and forest degradation, biodiversity loss, and may contaminate local and international waters.
- The manufacture of electronics and disposal at end-of-life are a primary source of toxic chemicals released into the environment, including mercury, POPs, uPOPs, and heavy metals. E-waste is now the fastest growing waste stream globally, with only about 20 percent soundly managed.

[91] Based on Moser et al., 2015; UNEP, 2019; Moser & Jakl, 2015; UNIDO, 2016; Schwager et al., 2016; Schwager et al., 2017; Moser et al., 2014; OECD, 2017

[92] Based on Balde et al., 2017; Lundgren, 2012; WEF, 2019; WEF et al., 2014; EMF, 2018

- The electronics sector involves waste management, environmental legislation and policies, manufacturers, consumer behavior, health, job creation, economic growth, technical know-how, and institutional capacity. Addressing sustainability requires consideration of all the elements in the system, and not just focusing on downstream interventions such as e-waste collection and recycling.

- The circular economy aims to keep resources in use for as long as possible, extract the maximum value from them while in use, and recover and regenerate products and materials at the end of their service life – is a system thinking approach that can be deployed in the electronics sector.
- Interventions include policies and regulations, e.g., extended producer responsibility combined with innovative business models, such as device leasing and product-as-a-service (e.g., Dell for personal computers and Philips and Signify for lighting systems). These provide economic incentives for manufacturers to emphasize durability, upgradability, repairability, ease of disassembly, and avoidance of hazardous chemicals during product design, as well as the collection and recycling of products at their end-of-life.
- Other interventions involve developing policies, standards, and incentives to promote the manufacture or importation of electronic products manufactured using the circular economy approach, strengthening the capacity of regulators and enforcement agents (e.g., customs officers) to enforce circular policies and standards, and providing information and incentives to help consumers make informed purchasing decisions.
- Implementing these solutions can deliver multiple environmental and socio-economic benefits. For example, a combination of improved product design, retention of materials within a closed-loop, and innovative business models, can help align environmental and economic objectives, including improving resource efficiency, reducing chemical pollution, and provision of socio-economic benefits such as improved occupational safety, prevention of avoidable healthcare costs, and creation of decent jobs.

4.0. Capturing the benefits of chemicals and waste projects

In addition to delivering chemicals and waste global environmental benefits, GEF chemicals and waste projects deliver GEBs in other GEF focal areas – biodiversity, land degradation, climate change, and international waters. Furthermore, these projects can also deliver local environmental benefits, for example, better air and water quality, and socio-economic benefits, such as jobs, improved livelihoods, and health. However, current GEF metrics do not capture all the possible environmental and socio-economic benefits achievable through its chemicals and waste investments. STAP seeks to help ensure these co-benefits are considered from project design through implementation and evaluation of project outcomes.

4.1. GEF-7 chemicals and waste result framework

Box 3.2 presents the GEF core indicators and sub-indicators for chemicals and waste (the full set of indicators for all focal areas is in annex A). These indicators measure: the amount of chemicals reduced, eliminated, or avoided; the number of countries with legislation and policies related to chemicals of interest to the GEF; and the number of low- or non-chemical systems and emission control technologies/practices implemented through GEF projects. However, these indicators do not capture non-chemicals and waste GEBs, or local environmental and socio-economic benefits.

The environmental impact of reducing or eliminating chemicals will vary considerably with the ecological context. For example, the type of ecosystem influences how mercury is transformed, stored or distributed in the environment (that is, methylation, bioaccumulation, biomagnification, or burial).[93] Accounting fully for the impacts of projects would require a detailed assessment of the effects of reduced or eliminated chemicals on the local ecosystem (e.g., air and water quality) and on local communities (e.g., health and food safety and security). Chemicals and waste projects would, therefore, need to include descriptions of the local ecosystem and socio-economic dimensions of the communities at project locations and present the possible benefits to ecosystems and wellbeing of the local people, as well as metrics for measuring these benefits.

Box 3.2. The GEF-7 chemicals and waste indicators

Reduction, disposal/destruction, phase out, elimination and avoidance of chemicals of global concern and their waste in the environment and in processes, materials, and products (metric tons of toxic chemicals reduced)

Sub-Indicators:

- *Solid and liquid Persistent Organic Pollutants (POPs) and POPs containing materials and products removed or disposed (POPs type)*
- *Quantity of mercury reduced*
- *Hydrochlorofluorocarbons reduced/phased out*
- *Number of countries with legislation and policy implemented to control chemicals and waste*
- *Number of low-chemical/non-chemical systems implemented, particularly in food production, manufacturing, and cities*

Reduction, avoidance of emissions of POPS to air from point and non-point sources (grams of toxic equivalent gTEQ)

Sub-Indicators:

- *Number of countries with legislation and policies implemented to control emissions of POPs to air*
- *Number of emission control technologies/practices implemented*

4.2 Capturing GEBs and the co-benefits of chemicals and waste interventions

The six examples below illustrate the possible co-benefits from chemicals and waste interventions, and the need for appropriate indicators to capture the them.

(i) **Projects to improve the manufacture and use of products**, e.g., plastics, electronics, or textiles, deliver chemicals and waste benefits and may improve energy efficiency and reduce greenhouse gas emissions (e.g., by reducing plastic production using fossil-fuel).

[93] Driscoll et al., 2007; Eagles-Smith et al., 2016; Ward et al., 2010; Adams et al., 2019

Similarly, eliminating ozone-depleting substances helps the stratospheric ozone layer to recover, and may also reduce greenhouse gas emissions and improve the energy efficiency of equipment (see section 2.3).

The GEF-7 climate change indicators (greenhouse gas emissions mitigated – metric tons of CO2 equivalent and energy saved – megajoules) and the chemicals and waste indicator (hydrochlorofluorocarbons reduced/phased out) are sufficient to capture these benefits.

(ii) **Pesticide and industrial POPs** affect all GEF focal areas. Using systems thinking approaches such as integrated pest management (IPM),[94] agroecology,[95] green chemistry, or the circular economy can yield co-benefits in biodiversity, international waters, and land degradation.

These co-benefits can be quantitatively captured by current GEF-7 core indicators, including the area of land restored, area of landscapes under improved practices, and area of marine habitat under improved practices to benefit biodiversity (annex A). The GEF-7 results framework also provides for a qualitative assessment of GEBs to capture specific benefits.

The evaluation of improved ecosystem services could offer further insights. For example, assessing how reduced pesticide use (through IPM or agroecology) or decreased POP use (through green chemistry) can lead to better freshwater quality and improved local biodiversity. Practical guidance is available on how to develop indicators for ecosystem services, as part of monitoring and reporting (through stakeholder engagement, policy analysis, and conceptual models).[96]

(iii) **Incomplete combustion of medical, municipal, and hazardous wastes** is responsible for uPOPs emissions, and produces greenhouse gas emissions, as well as causing air pollution, as do point emission sources of mercury, such as coal-fired power plants and cement kilns.

The climate change indicator captures the reduction in greenhouse gas emissions. And improved air quality could be captured by measuring the reduction in relevant air pollutants. Health metrics, such as avoided adverse outcomes, disability-adjusted life years (DALYs), and monetized impacts, could be used to assess the human health benefits of improved air quality.[97]

(iv) **Artisanal and small-scale gold mining** is linked to deforestation, land degradation, biodiversity loss, and fresh and international water pollution.

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[94] Integrated pest management is a sustainable approach that uses an understanding of the ecological relationship between crops, pests, and the environment to develop pest management strategies that combine biological, cultural, physical and chemical options, in order to minimize socioeconomic and environmental risks caused by pests.

[95] Agroecology uses understanding of interactions of all important biophysical, technical and socioeconomic components of farming systems to design and manage agricultural production in a way that is productive, while not damaging nature's goods and services.

[96] For example, Layke, 2009; Brown et al., 2014; Berghöfer & Schneider, 2015

[97] Martenies et al., 2020

Projects can deliver multiple benefits in these focal areas and also socio-economic benefits, for example, improved food security, increased food safety, and better and healthier livelihoods.

The GEF-7 indicator (area of landscapes under improved practices) can capture some of the biodiversity and land degradation GEBs. But the freshwater indicator (commitments by countries to cooperative management of shared water systems) would not capture freshwater benefits. And the GEF socio-economic indicator (number of beneficiaries) would not capture the benefits of, for example, improved food security and better livelihoods.

Indicators that capture freshwater co-benefits (e.g., physicochemical condition of, diversity of organism in, and ecosystems services provided by freshwater[98]) would provide a more complete account of benefits.

(v) **Circular economy chemicals and waste interventions** for transformational change (e.g., in the plastics, textile, or electronic sectors) can lead to resource efficiency, reduced depletion of natural resources, decreased environmental pollution, and lower greenhouse gas emissions.

While the GEF-7 core indicators for chemicals and waste (Box 3.4) and those for other focal areas (Annex A) will capture the decreased environmental pollution and lower greenhouse gas emissions benefits, the do not easily capture the resource efficiency and reduced depletion of natural resources benefits.

Indicators such as the amount of materials, water, and energy used, increased recycling rate, and greenhouse gas emitted per product could be used to account for these benefits. [99]

(vi) **Chemicals and waste projects can also deliver significant socio-economic benefits**, for example, improved food safety and security, enhanced human health, job creation, better occupational safety, prevention of avoidable healthcare costs, improved livelihoods, and better wellbeing.

The existing GEF-7 indicator for socio-economic benefits (number of direct beneficiaries disaggregated by gender as co-benefit of GEF investment) is intended to capture these socio-economic co-benefits.

Socio-economic benefits could be reported quantitatively or qualitatively, including improved agricultural productivity, avoided adverse health outcomes or improved DALYs, number of jobs created, improvement in natural capital (e.g., land, water, biological resources), and increased incomes.

5.0 Recommendations

The GEF's mandate is to maximize global environmental benefits, and it is possible to capture co-benefits without detracting from this core mandate. Evaluating and measuring co-benefits will provide additional justification for GEF investments and will increase the return on investment. It would also show the GEF

[98] See for instance, Canning & Death 2019; https://www.freshwaterhealthindex.org/indicators, for examples of metrics for measuring freshwater health.
[99] For example, Flachenecker et al., 2018; Behrens et al., 2015; Huysman et al., 2015; Bizikova et al. 2015.

having greater impact, not only on the environment but also on the welfare and sustainable development of the local communities where projects are located, and also provides an opportunity for getting better buy-in, engagement, and political support at the local and national levels.

To ensure that more of the benefits from GEF chemicals and waste projects are properly captured, STAP makes the following recommendations:[100]

In the near-term, the GEF should consider the following in the design of projects:

- **Apply systems thinking**: devise a logical sequence of interventions, which is responsive to changing circumstances. Address inter-connected environmental, social, economic, and governance challenges across sectors in design and implementation, with an eye towards resilience, transformational and enduring change.
- **Develop a check list of environmental and socio-economic benefits** for developers to consider identifying at the outset in designing projects, and to encourage them to think about suitable metrics for capturing co-benefits.
- **Use qualitative, and where possible quantitative, indicators of co-benefits** to ensure that achieved benefits are presented with adequate details, context, and robustness. Qualitative indicators would be useful in reporting benefits that may not be easily captured quantitatively, e.g., improvement in natural capital, better livelihoods, and improved human health.
- **Allow flexibility in using indicators** to capture co-benefits where suitable indicators are not included in the GEF result framework. (The GEF-7 results architecture encourages this, but it has not been widely adopted.)
- **Build capacity within the GEF partnership** on systems thinking, mainstreaming co-benefits, and developing indicators to capture co-benefits, and encourage bringing in expertise in the social sciences, and health.

Looking further ahead, the GEF could consider the following:

- **Strengthen the GEF indicators framework** to include both GEBs, and environmental and socio-economic co-benefit, for example, improvements in air and freshwater, more efficient use of resources, human health, and the number of jobs created.
- **Develop methodologies for assessing the direct and indirect environmental and socio-economic benefits of GEF investments**, for example, field studies and modeling to evaluate improvements in the environment or ecosystem services due to better management of chemicals and waste.
- **Adopt qualitative analytical methods**[101]**,** for example, collecting data through interviews, focus groups, surveys, and other forms of participatory approaches during project implementation and evaluation. This would be particularly useful for assessing socio-economic benefits such as improved food security, livelihoods, and wellbeing.

[100] These recommendations have been tailored to the chemicals and waste focal area of the GEF but are also applicable to all of GEF's work.
[101] "Qualitative monitoring and evaluation methods involve collecting and analyzing data in the form of words rather than numbers. It involves managing, sorting and interpreting qualitative data and can be carried out at any stage of a program or project cycle from design and planning through to impact assessment (Allen and Lopez 2017).

- **Develop or adopt composite indicators.** This could combine a number of individual indicators into a single index[102], to measure the overall impact of a project on the global environment and on society. Or the GEF could adopt existing composite indicators, such as the Environmental Performance Index,[103] Ecological Footprint Index,[104] or Living Planet Index[105].
- **Develop science-based targets for chemicals and waste,** working with the chemicals MEAs and SAICM, following the example set by the Montreal Protocol, UNFCCC, and CBD.

[102] OECD, 2008
[103] See: https://epi.yale.edu/. Also: Schmiedeknecht, 2013.
[104] See: https://www.footprintnetwork.org/our-work/ecological-footprint/
[105] See: https://livingplanetindex.org/home/index

Annex A: The GEF-7 core indicators and sub-indicators

1. Terrestrial protected areas created or under improved management for conservation and sustainable use (hectares)

Sub-Indicators:

Terrestrial protected areas newly created;
Terrestrial protected areas under improved management effectiveness

2. Marine protected areas created or under improved management for conservation and sustainable use (hectares)

Sub-Indicators:

Marine protected areas newly created
Marine protected areas under improved management effectiveness

3. Area of land restored (hectares)

Sub-Indicators:

Area of degraded agricultural lands restored
Area of forest and forest land restored
Area of natural grass and shrublands restored
Area of wetlands (including estuaries and mangroves) restored

4. Area of landscapes under improved practices (hectares; excluding protected areas)

Sub-Indicators:

Area of landscapes under improved management to benefit biodiversity (qualitative assessment, non-certified)
Area of landscapes that meet national or international third-party certification and that incorporates biodiversity considerations
Area of landscapes under sustainable land management in production systems
Area of High Conservation Value forest loss avoided

5. Area of marine habitat under improved practices to benefit biodiversity (hectares; excluding protected areas)

Sub-Indicators:

Number of fisheries that meet national or international third-party certification that incorporates biodiversity considerations
Number of Large Marine Ecosystems with reduced pollution and hypoxia
Amount of Marine Litter Avoided

6. Greenhouse gas emissions mitigated (metric tons of carbon dioxide equivalent)

Sub-Indicators:

Carbon sequestered, or emissions avoided in the sector of Agriculture, Forestry and Other Land Use
Emissions avoided outside Agriculture, Forestry and Other Land Use (AFOLU) sector
Energy saved
Increase in installed renewable energy capacity per technology

7. Number of shared water ecosystems (fresh or marine) under new or improved cooperative management

Sub-Indicators:

Level of Transboundary Diagnostic Analysis and Strategic Action Program formulation and implementation
Level of regional legal agreements and regional management institution(s) to support its implementation
Level of national/local reforms and active participation of Inter-Ministerial Committees
Level of engagement in IW:LEARN through participation and delivery of key products

8. Globally over-exploited fisheries moved to more sustainable levels (metric tons)

9. Reduction, disposal/destruction, phase out, elimination and avoidance of chemicals of global concern and their waste in the environment and in processes, materials, and products (metric tons of toxic chemicals reduced)

Sub-Indicators:

Solid and liquid Persistent Organic Pollutants (POPs) removed or disposed (POPs type)
Quantity of mercury reduced
Hydrochlorofluorocarbons reduced/phased out
Number of countries with legislation and policy implemented to control chemicals and waste
Number of low-chemical/non-chemical systems implemented, particularly in food production, manufacturing, and cities

Quantity of products/materials containing POPs/Mercury directly avoided

10. Reduction, avoidance of emissions of POPs to air from point and non-point sources (grams of toxic equivalent gTEQ)

Sub-Indicators:

Number of countries with legislation and policies implemented to control emissions of POPs to air

Number of emission control technologies/practices implemented

11. Number of direct beneficiaries disaggregated by gender as co-benefit of GEF investment

References

Adams, E.M., Williams, K.A., Olsen, O.J., Evers, D.C., 2020. Mercury exposure in migrating songbirds: correlations with physical condition. Ecotoxicology, DOI: 10.1007/s10646-020-02190-8

Agnan, Y., Le Dantec, T., Moore, C. W., Edwards, G. C., & Obrist, D. (2016). New Constraints on Terrestrial Surface–Atmosphere Fluxes of Gaseous Elemental Mercury Using a Global Database. Environmental Science & Technology, 50(2), 507–524. https://doi.org/10.1021/acs.est.5b04013

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. Interdisciplinary Toxicology, 2(1), 1–12. https://doi.org/10.2478/v10102-009-0001-7

Alaee, M. (Ed.). (2016). Dioxin and Related Compounds: Special Volume in Honor of Otto Hutzinger (Vol. 49). Springer International Publishing. https://doi.org/10.1007/978-3-319-23889-0

Alava, J. J., Cisneros-Montemayor, A. M., Sumaila, U. R., & Cheung, W. W. L. (2018). Projected amplification of food web bioaccumulation of MeHg and PCBs under climate change in the Northeastern Pacific. Scientific Reports, 8(1), 13460. https://doi.org/10.1038/s41598-018-31824-5

Almeida, M. D., Marins, R. V., Paraquetti, H. H., Bastos, W. R., & Lacerda, L. D. (2009). Mercury degassing from forested and open field soils in Rondônia, Western Amazon, Brazil. Chemosphere, 77(1), 60–66.

Asner, G. P., & Tupayachi, R. (2016). Accelerated losses of protected forests from gold mining in the Peruvian Amazon. Environmental Research Letters, 12(9), 094004. https://doi.org/10.1088/1748-9326/aa7dab

Asner, G. P., Llactayo, W., Tupayachi, R., & Luna, E. R. (2013). Elevated rates of gold mining in the Amazon revealed through high-resolution monitoring. Proceedings of the National Academy of Sciences, 110(46), 18454. https://doi.org/10.1073/pnas.1318271110

Balde, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The Global E-waste Monitor 2017. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

Banerjee, A., Fyfe, J.C., Polvani, L.M., Waugh, D., Chang, K. 2020. A pause in Southern Hemisphere circulation trends due to the Montreal Protocol. Nature, 579, 544–548.

Bancroft, B. A., Baker, N. J., & Blaustein, A. R. (2007). Effects of UVB radiation on marine and freshwater organisms: A synthesis through meta-analysis. Ecology Letters, 10(4), 332–345. https://doi.org/10.1111/j.1461-0248.2007.01022.x

Barra, R., & Leonard, S. A. (2018). Plastics and the circular economy. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC. 10.13140/RG.2.2.11515.57128

Behrens, A., Taranic, I., Rizos, V. 2015. “Resource Efficiency Indicators for Policy-Making.” Centre for European Policy Studies Policy Brief. https://www.ceps.eu/download/publication/?id=9155&pdf=WD415.pdf.

Beketov, M. A., Kefford, B. J., Schafer, R. B., & Liess, M. (2013). Pesticides reduce regional biodiversity of stream invertebrates. Proceedings of the National Academy of Sciences, 110(27), 11039–11043. https://doi.org/10.1073/pnas.1305618110

Berghöfer A, Schneider A, 2015. Indicators for Managing Ecosystem Services – Options & Examples. ValuES Project Report. Helmholtz Zentrum für Umweltforschung (UFZ) GmbH, Leipzig, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn. Germany. 49pp

Bhadouria, B. S., Mathur, V. B., & Kaul, R. (2012). Monitoring of organochlorine pesticides in and around Keoladeo National Park, Bharatpur, Rajasthan, India. Environmental Monitoring and Assessment, 184(9), 5295–5300. https://doi.org/10.1007/s10661-011-2340-z

Bierbaum, R., A. Cowie, R. Barra, B. Ratner, R. Sims, M. Stocking, G. Durón, S. Leonard, and C. Whaley. 2018. Integration: to solve complex environmental problems. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC.

Bizikova, Livia, Laszlo Pinter, G. A. Huppé, H. Schandl, C. Arden-Clarke, and S. Averous. 2015. “Sustainable Consumption and Production Indicators for the Future SDGs.” Nairobi: UNEP.

Bonnet, C., Babut, M., Férard, J.-F., Martel, L., & Garric, J. (2000). Assessing the potential toxicity of resuspended sediment. Environmental Toxicology and Chemistry: An International Journal, 19(5), 1290–1296.

Booth, S., Hui, J., Alojado, Z., Lam, V., Cheung, W., Zeller, D., Steyn, D., & Pauly, D. (2013). Global deposition of airborne dioxin. Marine Pollution Bulletin, 75(1–2), 182–186. https://doi.org/10.1016/j.marpolbul.2013.07.041

Bravo, Andrea Garcia, Loizeau, J.-L., Bouchet, S., Richard, A., Rubin, J. F., Ungureanu, V.-G., Amouroux, D., & Dominik, J. (2010). Mercury human exposure through fish consumption in a reservoir contaminated by a chlor-alkali plant: Babeni reservoir (Romania). Environmental Science and Pollution Research, 17(8), 1422–1432. https://doi.org/10.1007/s11356-010-0328-9

Brigden, K., Labunska, I., Santillo, D., & Johnston, P. (2008). Chemical contamination at e-waste recycling and disposal sites in Accra and Korforidua, Ghana. Greenpeace Research Laboratories Technical Note, 24.
Brown, C., B. Reyers, L. Ingwall-King, A. Mapendembe, J. Nel, P. O'Farrell, M. Dixon, and N. J. Bowles-Newark. 2014. "Measuring Ecosystem Services: Guidance on Devleoping Ecosystem Service Indicators." UNEP and Stockholm Resilience Centre. https://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/303/original/1850_ESI_Guidance_A4_WEB.pdf?1424707843.
Camacho, C., Maulvault, A. L., Santos, M. T., Barbosa, V., Fogaça, F. H. S., Pousão-Ferreira, P., Nunes, M. L., Rosa, R., & Marques, A. (2020). Mercury in Juvenile Solea senegalensis: Linking Bioaccumulation, Seafood Safety, and Neuro-Oxidative Responses under Climate Change-Related Stressors. Applied Sciences, 10(6), 1993. https://doi.org/10.3390/app10061993
Campbell, L., Dixon, D. G., & Hecky, R. E. (2003). A Review Of Mercury in Lake Victoria, East Africa: Implications for Human and Ecosystem Health. Journal of Toxicology and Environmental Health, Part B, 6(4), 325–356. https://doi.org/10.1080/10937400306474
Canning and Death, 2019. Ecosystem Health Indicators—Freshwater Environments. Encyclopedia of Ecology (2nd Edition), 1, 46-60. https://doi.org/10.1016/B978-0-12-409548-9.10617-7
Carpi, A., Lindberg, S. E., Prestbo, E. M., & Bloom, N. S. (1997). Methyl Mercury Contamination and Emission to the Atmosphere from Soil Amended with Municipal Sewage Sludge. Journal of Environmental Quality, 26(6), 1650–1655. https://doi.org/10.2134/jeq1997.00472425002600060027x
Connell, J. H. (1978). Diversity in Tropical Rain Forests and Coral Reefs. Science, 199(4335), 1302–1310. https://doi.org/10.1126/science.199.4335.1302
Corsolini, S., & Sarà, G. (2017). The trophic transfer of persistent pollutants (HCB, DDTs, PCBs) within polar marine food webs. Chemosphere, 177, 189–199. https://doi.org/10.1016/j.chemosphere.2017.02.116
Delcour, I., Spanoghe, P., & Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. Food Research International, 68, 7–15. https://doi.org/10.1016/j.foodres.2014.09.030
DeLorenzo, M. E., Scott, G. I., & Ross, P. E. (2001). Toxicity of pesticides to aquatic microorganisms: A review. Environmental Toxicology and Chemistry, 20(1), 84–98. https://doi.org/10.1002/etc.5620200108
Desforges, J.-P., Hall, A., McConnell, B., Rosing-Asvid, A., Barber, J. L., Brownlow, A., De Guise, S., Eulaers, I., Jepson, P. D., Letcher, R. J., Levin, M., Ross, P. S., Samarra, F., Víkingson, G., Sonne, C., & Dietz, R. (2018). Predicting global killer whale population collapse from PCB pollution. Science, 361(6409), 1373–1376. https://doi.org/10.1126/science.aat1953
Dethier, E. N., Sartain, S. L., & Lutz, D. A. (2019). Heightened levels and seasonal inversion of riverine suspended sediment in a tropical biodiversity hot spot due to artisanal gold mining. Proceedings of the National Academy of Sciences, 116(48), 23936. https://doi.org/10.1073/pnas.1907842116
Diringer, S. E., Feingold, B. J., Ortiz, E. J., Gallis, J. A., Araújo-Flores, J. M., Berky, A., Pan, W. K. Y., & Hsu-Kim, H. (2015). River transport of mercury from artisanal and small-scale gold mining and risks for dietary mercury exposure in Madre de Dios, Peru. Environmental Science: Processes & Impacts, 17(2), 478–487. https://doi.org/10.1039/C4EM00567H
Dorneles, P. R., Sanz, P., Eppe, G., Azevedo, A. F., Bertozzi, C. P., Martínez, M. A., Secchi, E. R., Barbosa, L. A., Cremer, M., Alonso, M. B., Torres, J. P. M., Lailson-Brito, J., Malm, O., Eljarrat, E., Barceló, D., & Das, K. (2013). High accumulation of PCDD, PCDF, and PCB congeners in marine mammals from Brazil: A serious PCB problem. Science of The Total Environment, 463–464, 309–318. https://doi.org/10.1016/j.scitotenv.2013.06.015
Driscoll et al., 2013. Mercury as a Global Pollutant: Sources, Pathways, and Effects. Environ Sci Technol. 47, 4967–4983.
Driscoll, Charles T., Young-Ji Han, Celia Y. Chen, David C. Evers, Kathleen Fallon Lambert, Thomas M. Holsen, Neil C. Kamman, and Ronald K. Munson. 2007. "Mercury Contamination in Forest and Freshwater Ecosystems in the Northeastern United States." BioScience 57 (1): 17–28. https://doi.org/10.1641/B570106.
Eagles-Smith, Collin A., James G. Wiener, Chris S. Eckley, James J. Willacker, David C. Evers, Mark Marvin-DiPasquale, Daniel Obrist, et al. 2016. "Mercury in Western North America: A Synthesis of Environmental Contamination, Fluxes, Bioaccumulation, and Risk to Fish and Wildlife." Science of The Total Environment 568 (October): 1213–26. https://doi.org/10.1016/j.scitotenv.2016.05.094.
Edwards, D. P., Sloan, S., Weng, L., Dirks, P., Sayer, J., & Laurance, W. F. (2014). Mining and the African Environment. Conservation Letters, 7(3), 302–311. https://doi.org/10.1111/conl.12076
EMF. (2018). Circular consumer electronics: An initial exploration. Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/publications/circular-consumer-electronics-an-initial-exploration
EMF. (2019). Artificial intelligence and the circular economy—AI as a tool to accelerate the transition. Ellen MacArthur Foundation. http://www.ellenmacarthurfoundation.org/publications
Engle, M. A., Gustin, M. S., & Zhang, H. (2001). Quantifying natural source mercury emissions from the Ivanhoe Mining District, north-central Nevada, USA. Atmospheric Environment, 35(23), 3987–3997.
Esdaile, L. J., & Chalker, J. M. (2018). The Mercury Problem in Artisanal and Small-Scale Gold Mining. Chemistry – A European Journal, 24(27), 6905–6916. https://doi.org/10.1002/chem.201704840
Espejo, W., Padilha, J. de A., Gonçalves, R. A., Dorneles, P. R., Barra, R., Oliveira, D., Malm, O., Chiang, G., & Celis, J. E. (2019). Accumulation and potential sources of lead in marine organisms from coastal ecosystems of the Chilean Patagonia and Antarctic Peninsula area. Marine Pollution Bulletin, 140, 60–64. https://doi.org/10.1016/j.marpolbul.2019.01.026

Evans, M., Muir, D., Brua, R. B., Keating, J., & Wang, X. (2013). Mercury trends in predatory fish in great slave lake: The influence of temperature and other climate drivers. Environmental Science and Technology, 47(22), 12793–12801. https://doi.org/10.1021/es402645x
Flachenecker, Florian, Jun Rentschler, and Willem de Kleuver. 2018. “Monitoring Resource Efficiency Developments: Indicators, Data, and Trends.” In Investing in Resource Efficiency, 31–50. Springer.
Fletcher, K. (2009). Systems change for sustainability in textiles. In Sustainable Textiles (pp. 369–380). Elsevier. https://doi.org/10.1533/9781845696948.2.369
Gleason, D. F., & Wellington, G. M. (1993). Ultraviolet radiation and coral bleaching. Nature, 365(6449), 836–838. https://doi.org/10.1038/365836a0
Goyal, R., England, M. H., Sen Gupta, A., & Jucker, M. (2019). Reduction in surface climate change achieved by the 1987 Montreal Protocol. Environmental Research Letters, 14(12), 124041. https://doi.org/10.1088/1748-9326/ab4874
Guigue, C., Tedetti, M., Dang, D. H., Mullot, J.-U., Garnier, C., & Goutx, M. (2017). Remobilization of polycyclic aromatic hydrocarbons and organic matter in seawater during sediment resuspension experiments from a polluted coastal environment: Insights from Toulon Bay (France). Environmental Pollution, 229, 627–638.
Häder, D., Worrest, R., Kumar, H. D., & Smith, R. (1991). Effects of enhanced solar-ultraviolet radiation on aquatic ecosystems. Ambio, 24, 1774–1800. https://doi.org/10.1111/j.1751-1097.1991.tb08931.x
Hendryx, M., Zullig, K. J., & Luo, J. (2020). Impacts of Coal Use on Health. Annual Review of Public Health, 41(1), 397–415. https://doi.org/10.1146/annurev-publhealth-040119-094104
Holz, A., Paritsis, J., Mundo, I. A., Veblen, T. T., Kitzberger, T., Williamson, G. J., Aráoz, E., Bustos-Schindler, C., González, M. E., Grau, H. R., & Quezada, J. M. (2017). Southern Annular Mode drives multicentury wildfire activity in southern South America. Proceedings of the National Academy of Sciences, 114(36), 9552–9557. https://doi.org/10.1073/pnas.1705168114
Hudelson, K., Ashta, N.M., Leonard, S.A., Scheringer, M. 2020. Delivering multiple benefits through the sound management of chemicals and waste. Background report. International Panel on Chemical Pollution, Zurich, Switzerland.
Huysman, Sofie, Serenella Sala, Lucia Mancini, Fulvio Ardente, Rodrigo A.F. Alvarenga, Steven De Meester, Fabrice Mathieux, and Jo Dewulf. 2015. “Toward a Systematized Framework for Resource Efficiency Indicators.” Resources, Conservation and Recycling 95 (February): 68–76. https://doi.org/10.1016/j.resconrec.2014.10.014.
Jepson, P. D., & Law, R. J. (2016). Persistent pollutants, persistent threats. Science, 352(6292), 1388–1389. https://doi.org/10.1126/science.aaf9075
Kawakami, T. (2019). DIFFUSION OF MERCURY FROM ARTISANAL SMALL-SCALE GOLD MINING (ASGM) SITES IN MYANMAR. International Journal of GEOMATE, 17(61). https://doi.org/10.21660/2019.61.4823
KEMI. (2013). Hazardous chemicals in textiles – report of a government assignment. Swedish Chemicals Agency (KEMI). https://www.kemi.se/global/rapporter/2013/rapport-3-13-textiles.pdf
Kravchenko, J., & Lyerly, H. K. (2018). The Impact of Coal-Powered Electrical Plants and Coal Ash Impoundments on the Health of Residential Communities. North Carolina Medical Journal, 79(5), 289. https://doi.org/10.18043/ncm.79.5.289
Kumar, K. S., Kannan, K., Paramasivan, O. N., Sundaram, V. P. S., Nakanishi, J., & Masunaga, S. (n.d.). Polychlorinated Dibenzo-p-Dioxins, Dibenzofurans, and Polychlorinated Biphenyls in Human Tissues, Meat, Fish, and Wildlife Samples from India. 8.
Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., True, J. D., Kelly, L. A., Ahmad, A., Jompa, J., & Harvell, C. D. (2018). Plastic waste associated with disease on coral reefs. Science, 359(6374), 460–462. https://doi.org/10.1126/science.aar3320
Landrigan, P.J., Goldman, L.R. 2011. Children’s Vulnerability to Toxic Chemicals: A Challenge And Opportunity To Strengthen Health And Environmental Policy. Health Affairs, 30, 842-850. DOI: 10.1377/hlthaff.2011.0151
Layke, Christian. 2009. “Measuring Nature’s Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators.” WRI. http://re.indiaenvironmentportal.org.in/files/measuring_natures_benefits.pdf
Leonard, A. W., Hyne, R. V., Lim, R. P., Pablo, F., & Van den Brink, P. J. (2000). Riverine endosulfan concentrations in the Namoi River, Australia: Link to cotton field runoff and macroinvertebrate population densities. Environmental Toxicology and Chemistry, 19(6), 1540–1551. https://doi.org/10.1002/etc.5620190610
Liang, R., Chen, J., Shi, Y., Lu, Y., Sarvajayakesavalu, S., Xu, X., Zheng, X., Khan, K., & Su, C. (2018). Toxicological effects on earthworms (Eisenia fetida) exposed to sub-lethal concentrations of BDE-47 and BDE-209 from a metabolic point. Environmental Pollution, 240, 653–660. https://doi.org/10.1016/j.envpol.2018.04.145
Lindberg, S. E., & Stratton, W. J. (1998). Atmospheric Mercury Speciation: Concentrations and Behavior of Reactive Gaseous Mercury in Ambient Air. Environmental Science & Technology, 32(1), 49–57. https://doi.org/10.1021/es970546u
Liu, J., Wang, D., Zhang, J., Liem-Nguyen, V., Huang, R., & Jiang, T. (2020). Evaluation of Hg methylation in the water-level-fluctuation zone of the Three Gorges Reservoir region by using the MeHg/HgT ratio. Ecotoxicology and Environmental Safety, 195, 110468. https://doi.org/10.1016/j.ecoenv.2020.110468
Liu, K., Wang, S., Wu, Q., Wang, L., Ma, Q., Zhang, L., Li, G., Tian, H., Duan, L., & Hao, J. (2018). A Highly Resolved Mercury Emission Inventory of Chinese Coal-Fired Power Plants. Environmental Science & Technology, 52(4), 2400–2408. https://doi.org/10.1021/acs.est.7b06209
Lundgren, K. (2012). The global impact of e-waste: Addressing the challenge. International Labour Office, Geneva.
Lundgren, K. (2012). The global impact of e-waste: Addressing the challenge. International Labour Office, Geneva.

M.F. Fahnestock, J.G. Bryce, C.K. McCalley, M. Montesdeoca, S. Bai, Y. Li, C.T. Driscoll, P.M. Crill, V.I. Rich, R.K. Varner. 2019. Mercury reallocation in thawing subarctic peatlands. Geochemical Perspectives Letters v11 | doi: 10.7185/geochemlet.1922
MacSween, K., Edwards, G. C., & Howard, D. A. (2020). Up-scaling mercury emissions from terrestrial surfaces as a response to sustained temperature increase. Atmospheric Environment, 223, 117190. https://doi.org/10.1016/j.atmosenv.2019.117190
Manatsa, D., Morioka, Y., Behera, S. K., Yamagata, T., & Matarira, C. H. (2013). Link between Antarctic ozone depletion and summer warming over southern Africa. Nature Geoscience, 6(11), 934–939. https://doi.org/10.1038/ngeo1968
Martenies, S.E., Wilkins, D., Batterman, S.A. 2020. Health impact metrics for air pollution management strategies. Environ Int. 85, 84–95. doi: 10.1016/j.envint.2015.08.013
Martín, J. A. [Rodríguez, & Nanos, N. (2016). Soil as an archive of coal-fired power plant mercury deposition. Journal of Hazardous Materials, 308, 131–138. https://doi.org/10.1016/j.jhazmat.2016.01.026
Matzrafi, M. (2019). Climate change exacerbates pest damage through reduced pesticide efficacy: Reduced pesticide efficacy under climate change. Pest Management Science, 75(1), 9–13. https://doi.org/10.1002/ps.5121
Megharaj, M., Kantachote, D., Singleton, I., & Naidu, R. (2000). E⁄ects of long-term contamination of DDT on soil micro¯ora with special reference to soil algae and algal transformation of DDT. Environmental Pollution, 8.
Moser, F., & Jakl, T. (2015). Chemical leasing—A review of implementation in the past decade. Environmental Science and Pollution Research, 22(8), 6325–6348. https://doi.org/10.1007/s11356-014-3879-3
Moser, F., Jakl, T., Joas, R., & Dondi, F. (2014). Chemical Leasing business models and corporate social responsibility. Environmental Science and Pollution Research, 21(21), 12445–12456. https://doi.org/10.1007/s11356-014-3126-y
Moser, F., Karavezyris, V., & Blum, C. (2015). Chemical leasing in the context of sustainable chemistry. Environmental Science and Pollution Research, 22(9), 6968–6988. https://doi.org/10.1007/s11356-014-3926-0
Nguyen, N. H., Beeton, R. J. S., & Halog, A. (2015). A systems thinking approach for enhancing adaptive capacity in small- and medium-sized enterprises: Causal mapping of factors influencing environmental adaptation in Vietnam's textile and garment industry. Environment Systems and Decisions, 35(4), 490–503. https://doi.org/10.1007/s10669-015-9570-5
Obrist, D., Kirk, J. L., Zhang, L., Sunderland, E. M., Jiskra, M., & Selin, N. E. (2018). A review of global environmental mercury processes in response to human and natural perturbations: Changes of emissions, climate, and land use. Ambio, 47(2), 116–140. https://doi.org/10.1007/s13280-017-1004-9
OECD. (2017). Economic Features of Chemical Leasing. https://www.oecd.org/chemicalsafety/risk-management/economic-features-of-chemical-leasing.pdf
Palacios-Torres, Y., Caballero-Gallardo, K., & Olivero-Verbel, J. (2018). Mercury pollution by gold mining in a global biodiversity hotspot, the Choco biogeographic region, Colombia. Chemosphere, 193, 421–430. https://doi.org/10.1016/j.chemosphere.2017.10.160
Papworth, S., Rao, M., Oo, M. M., Latt, K. T., Tizard, R., Pienkowski, T., & Carrasco, L. R. (2017). The impact of gold mining and agricultural concessions on the tree cover and local communities in northern Myanmar. Scientific Reports, 7(1), 46594. https://doi.org/10.1038/srep46594
Petrlik, J., Adu-Kumi, S., Hogarh, J., Akortia, E., Kuepouo, G., Behnisch, P., Bell, L., & DiGangi, J. (2019). Persistent organic pollutants (POPs) in eggs: Report from Africa.
Pickard, H. M., Criscitiello, A. S., Persaud, D., Spencer, C., Muir, D. C. G., Lehnherr, I., Sharp, M. J., Silva, A. O. D., & Young, C. J. (2020). Ice Core Record of Persistent Short-Chain Fluorinated Alkyl Acids: Evidence of the Impact From Global Environmental Regulations. Geophysical Research Letters, 47(10), e2020GL087535. https://doi.org/10.1029/2020GL087535
Poissant, L., Pilote, M., & Casimir, A. (1999). Mercury flux measurements in a naturally enriched area: Correlation with environmental conditions during the Nevada Study and Tests of the Release of Mercury From Soils (STORMS). Journal of Geophysical Research: Atmospheres, 104(D17), 21845–21857.
Ratner, B.D. and Stafford Smith, M. 2020. Multistakeholder dialogue for transformational change. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC.
Razi, K.H. A., & Hiroshi, M. (2012). Modeling of atmospheric dispersion of mercury from coal–fired power plants in Japan. Atmospheric Pollution Research, 3(2), 226–237. https://doi.org/10.5094/APR.2012.025
Robinson, S. A., & Erickson, D. J. (2015). Not just about sunburn – the ozone hole's profound effect on climate has significant implications for Southern Hemisphere ecosystems. Global Change Biology, 21(2), 515–527. https://doi.org/10.1111/gcb.12739
Roca, E., & Herva, D. M. (2015). Ecological footprints in the textile industry. In Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing (pp. 63–82). Elsevier. https://doi.org/10.1016/B978-0-08-100169-1.00003-4
Rohr, J.R., Johnson, P., Hickey, C.W., Helm, R.C. 2013. Implications of global climate change for natural resource damage assessment, restoration, and rehabilitation. Environmental Toxicology and Chemistry, Vol. 32, No. 1, pp. 93–101
Römbke, J., Schmelz, R. M., & Pélosi, C. (2017). Effects of Organic Pesticides on Enchytraeids (Oligochaeta) in Agroecosystems: Laboratory and Higher-Tier Tests. Frontiers in Environmental Science, 5, 20. https://doi.org/10.3389/fenvs.2017.00020
Roy Choudhury, A. K. (2014). Environmental Impacts of the Textile Industry and Its Assessment Through Life Cycle Assessment. In S. S. Muthu (Ed.), Roadmap to Sustainable Textiles and Clothing (pp. 1–39). Springer Singapore. https://doi.org/10.1007/978-981-287-110-7_1
Royer, S-J, Ferron, S., Wilson, S.T., Karl, D.M. 2018. Production of methane and ethylene from plastic in the environment. Plos One. https://doi.org/10.1371/journal.pone.0200574

Sajn, N. (2019). Environmental impact of the textile and clothing industry: What consumers need to know. European Parliamentary Research Service.
https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/633143/EPRS_BRI(2019)633143_EN.pdf
Sanei, H., Goodarzi, F., & Outridge, P. M. (2010). Spatial distribution of mercury and other trace elements in recent lake sediments from central Alberta, Canada: An assessment of the regional impact of coal-fired power plants. International Journal of Coal Geology, 82(1), 105–115. https://doi.org/10.1016/j.coal.2010.01.010
Schmiedeknecht M.H. (2013) Environmental Sustainability Index. In: Idowu S.O., Capaldi N., Zu L., Gupta A.D. (eds) Encyclopedia of Corporate Social Responsibility. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-28036-8_116
Schnitzler, J. G., Reckendorf, A., Pinzone, M., Autenrieth, M., Tiedemann, R., Covaci, A., Malarvannan, G., Ruser, A., Das, K., & Siebert, U. (2019). Supporting evidence for PCB pollution threatening global killer whale population. Aquatic Toxicology, 206, 102–104. https://doi.org/10.1016/j.aquatox.2018.11.008
Schroeder, W. H., & Munthe, J. (1998). Atmospheric mercury—An overview. Atmospheric Environment, 32(5), 809–822. https://doi.org/10.1016/S1352-2310(97)00293-8
Schuster, P. F., Schaefer, K. M., Aiken, G. R., Antweiler, R. C., Dewild, J. F., Gryziec, J. D., Gusmeroli, A., Hugelius, G., Jafarov, E., Krabbenhoft, D. P., Liu, L., Herman-Mercer, N., Mu, C., Roth, D. A., Schaefer, T., Striegl, R. G., Wickland, K. P., & Zhang, T. (2018). Permafrost Stores a Globally Significant Amount of Mercury. Geophysical Research Letters.
https://doi.org/10.1002/2017GL075571
Schwager, P., Decker, N., & Kaltenegger, I. (2016). Exploring Green Chemistry, Sustainable Chemistry and innovative business models such as Chemical Leasing in the context of international policy discussions. Current Opinion in Green and Sustainable Chemistry, 1, 18–21. https://doi.org/10.1016/j.cogsc.2016.07.005
Schwager, P., Dunjic, B., & Kaltenegger, I. (2017). Success and failure of the Chemical Leasing model in addressing sustainability challenges: Evidence from practice. Current Opinion in Green and Sustainable Chemistry, 8, 14–17.
https://doi.org/10.1016/j.cogsc.2017.08.001
Schwartz, G. E., Redfern, L. K., Ikuma, K., Gunsch, C. K., Ruhl, L. S., Vengosh, A., & Hsu-Kim, H. (2016). Impacts of coal ash on methylmercury production and the methylating microbial community in anaerobic sediment slurries. Environmental Science: Processes & Impacts, 18(11), 1427–1439.
Schwarzenbach RP, Gschwend PM, Imboden DM. 2003. Environmental Organic Chemistry. New York: Wiley. 1311 pp.
Shah, N., Wei. M., Letschert, V., Phadke, A. 2015. Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning. Ernest Orlando Lawrence Berkeley National Laboratory.
https://ies.lbl.gov/sites/default/files/lbnl-1003671.pdf
Shi, Y., Xu, X., Chen, J., Liang, R., Zheng, X., Shi, Y., & Wang, Y. (2018). Antioxidant gene expression and metabolic responses of earthworms (Eisenia fetida) after exposure to various concentrations of hexabromocyclododecane. Environmental Pollution, 232, 245–251. https://doi.org/10.1016/j.envpol.2017.09.039
Silverstein, K. (2018). Hurricane Florence Brings The Issue Of Coal Ash Back To The Surface. Forbes.
https://www.forbes.com/sites/kensilverstein/2018/09/18/hurricane-florence-brings-the-issue-of-coal-ash-back-to-the-surface/#9d17ad1fe361
Smith, R. C., & Baker, K. S. (1989). Stratospheric Ozone, Middle Ultraviolet Radiation and Phytoplankton Productivity. Oceanography, 2(2), 4–10. JSTOR.
Sorensen, J. A., Kallemeyn, L. W., & Sydor, M. (2005). Relationship between Mercury Accumulation in Young-of-the-Year Yellow Perch and Water-Level Fluctuations. Environmental Science & Technology, 39(23), 9237–9243.
https://doi.org/10.1021/es050471r
Ssebugere, P., Kiremire, B. T., Henkelmann, B., Bernhöft, S., Wasswa, J., Kasozi, G. N., & Schramm, K.-W. (2013). PCDD/Fs and dioxin-like PCBs in surface sediments from Lake Victoria, East Africa. Science of The Total Environment, 454–455, 528–533.
https://doi.org/10.1016/j.scitotenv.2013.03.046
St. Pierre, Kyra A., Zolkos, S., Shakil, S., Tank, S. E., St. Louis, V. L., & Kokelj, S. V. (2018). Unprecedented Increases in Total and Methyl Mercury Concentrations Downstream of Retrogressive Thaw Slumps in the Western Canadian Arctic. Environmental Science & Technology, 52(24), 14099–14109. https://doi.org/10.1021/acs.est.8b05348
Stafford Smith, M., et al. 2019a. Theory of Change primer. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC.
Stafford Smith, M., et al. 2019b. Achieving enduring outcomes from GEF investment. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC.
STAP, 2019. STAP guidance on climate risk screening. Scientific and Technical Advisory Panel to the Global Environment Facility, Washington, DC.
Stocking, M. et al. 2018. Managing knowledge for a sustainable global future. Scientific and Technical Advisory Panel to the Global Environment Facility. Washington, DC.
Stone, M. 2020. A plague of locusts has descended on East Africa. Climate change may be to blame. National Geographic.
https://www.nationalgeographic.com/science/2020/02/locust-plague-climate-science-east-africa/
Taiwo, A. M. (2019). A review of environmental and health effects of organochlorine pesticide residues in Africa. Chemosphere, 220, 1126–1140. https://doi.org/10.1016/j.chemosphere.2019.01.001

Toprak, T., & Anis, P. (2017). Textile industry's environmental effects and approaching cleaner production and sustainability, an overview. Journal of Textile Engineering & Fashion Technology, 2(4), 429–442. https://doi.org/10.15406/jteft.2017.02.00066
Toth, F., 2018. Innovation and the GEF: Scientific and Technical Advisory Panel to the Global Environment Facility, Washington, DC.
Tsui, M. T.-K., Uzun, H., Ruecker, A., Majidzadeh, H., Ulus, Y., Zhang, H., Bao, S., Blum, J. D., Karanfil, T., & Chow, A. T. (2020). Concentration and isotopic composition of mercury in a blackwater river affected by extreme flooding events. Limnology and Oceanography. https://doi.org/10.1002/lno.11445
UNEP, 1994, Regional Overview of Land-based Sources of Pollution in the Wider Caribbean Region, vol. 33, UNEP/CEP https://wedocs.unep.org/handle/20.500.11822/28660.
UNEP, 2012. The Montreal Protocol and the Green Economy. United Nations Environment Programme. https://wedocs.unep.org/handle/20.500.11822/21383
UNEP. (2019). Global Chemicals Outlook II. United Nations Environment Programme.
UNEP. (2019a). Global Mercury Assessment 2018 (p. 62). United Nations Environment Programme, Economy Division Chemicals and Health Branch
UNEP/AMAP. (2011). Climate Change and POPs: Predicting the Impacts. Report of the UNEP/AMAP Expert Group. Secretariat of the Stockholm Convention, Geneva. https://www.amap.no/documents/doc/climate-change-and-pops-predicting-the-impacts/753
UNESCO. (2020). Keoladeo National Park. United Nations Educational, Scientific and Cultural Organization. https://whc.unesco.org/en/list/340/
UNDP. 2011. Chemicals and gender. United Nations Development Programme. http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/chemicals-management/chemicals-and-gender/2011%20Chemical&Gender.pdf
UNIDO. (2016). Global promotion and implementation of chemical leasing business models in industry: 10 years outlook. United Nations Industrial Development Organization, Vienna.
Vallack, H. W., Bakker, D. J., Brandt, I., Broström-Lundén, E., Brouwer, A., Bull, K. R., Gough, C., Guardans, R., Holoubek, I., Jansson, B., Koch, R., Kuylenstierna, J., Lecloux, A., Mackay, D., McCutcheon, P., Mocarelli, P., & Taalman, R. D. F. (1998). Controlling persistent organic pollutants–what next? Environmental Toxicology and Pharmacology, 6(3), 143–175. https://doi.org/10.1016/S1382-6689(98)00036-2
Ward, D.M., Nislow, K.H., Chen, C.Y., Folt, C.L. 2010. Rapid, Efficient Growth Reduces Mercury Concentrations in Stream-Dwelling Atlantic Salmon, Transactions of the American Fisheries Society, 139:1, 1-10, DOI: 10.1577/T09-032.1
WEF, EMF, & McKinsey & Co. (2014). Towards the Circular Economy: Accelerating the scale-up across global supply chains. World Economic Forum, Geneva, Switzerland.
WEF. (2019). A New Circular Vision for Electronics Time for a Global Reboot. Platform for Accelerating the Circular Economy, World Economic Forum, Geneva, Switzerland.
Welch, E. B., & Spindler, J. C. (1964). DDT Persistence and Its Effect on Aquatic Insects and Fish after an Aerial Application. Journal (Water Pollution Control Federation), 36(10), 1285–1292. JSTOR.
World Health Organization. 2018. The public health impact of chemicals: knowns and unknowns. World Health Organization. https://www.who.int/publications/i/item/WHO-FWC-PHE-EPE-16.01-eng
WRI (2011, February 18). Marine Protected Areas in Coral Reef Regions Classified According to Management Effectiveness Rating. World Resources Institute. https://www.wri.org/resource/marine-protected-areas-coral-reef-regions-classified-according-management-effectiveness
Wu, W., Wu, P., Yang, F., Sun, D.-L., Zhang, D.-X., & Zhou, Y.-K. (2018). Assessment of heavy metal pollution and human health risks in urban soils around an electronics manufacturing facility. Science of The Total Environment, 630, 53–61. https://doi.org/10.1016/j.scitotenv.2018.02.183
Xiang, Y., Wang, Y., Zhang, C., Shen, H., & Wang, D. (2018). Water level fluctuations influence microbial communities and mercury methylation in soils in the Three Gorges Reservoir, China. Mercury Fate and Biogeochemistry, 68, 206–217. https://doi.org/10.1016/j.jes.2018.03.009
Xu, Y., Zaelke, D., Velders, G. J. M., & Ramanathan, V. (2013). The role of HFCs in mitigating 21st century climate change. Atmospheric Chemistry and Physics, 13(12), 6083–6089. https://doi.org/10.5194/acp-13-6083-2013
Yang, J., Takaoka, M., Sano, A., Matsuyama, A., & Yanase, R. (2018). Vertical Distribution of Total Mercury and Mercury Methylation in a Landfill Site in Japan. International Journal of Environmental Research and Public Health, 15(6), 1252. https://doi.org/10.3390/ijerph15061252
Zhang, J., Liu, N., Li, W., & Dai, B. (2011). Progress on cleaner production of vinyl chloride monomers over non-mercury catalysts. Frontiers of Chemical Science and Engineering, 5(4), 514–520. https://doi.org/10.1007/s11705-011-1114-z
Zhang, Y., Luo, X.-J., Wu, J.-P., Liu, J., Wang, J., Chen, S.-J., & Mai, B.-X. (2010). Contaminant pattern and bioaccumulation of legacy and emerging organhalogen pollutants in the aquatic biota from an e-waste recycling region in South China. Environmental Toxicology and Chemistry, 29(4), 852–859. https://doi.org/10.1002/etc.122
Zhao, Y., Li, Y., Qin, X., Lou, Q., & Qin, Z. (2016). Accumulation of polybrominated diphenyl ethers in the brain compared with the levels in other tissues among different vertebrates from an e-waste recycling site. Environmental Pollution, 218, 1334–1341. https://doi.org/10.1016/j.envpol.2016.08.091

Zimmerman, J.B., Anastas, P.T., Erythropel, H.C., Leitner, W. 2020. Designing for a green chemistry future. Science 367, 397–400