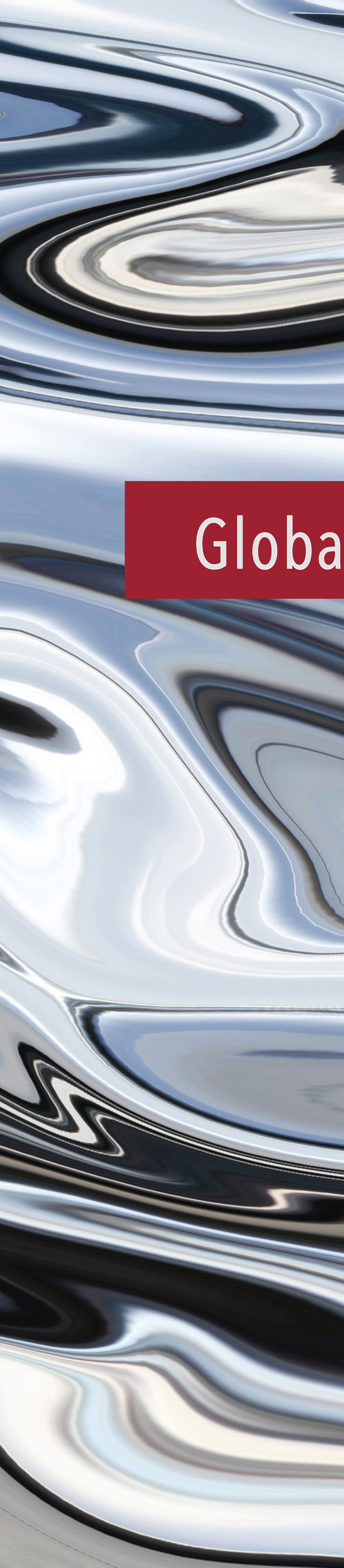

Global Mercury Inventory Synthesis

An Initial Examination of the MIA Mercury Inventories

2019

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Executive Summary

Mercury (Hg) is a ubiquitous, persistent pollutant of global concern known to cause adverse health effects and negatively impact ecosystem health and functioning. In order to address these challenges, a legally-binding global treaty known as the Minamata Convention on Mercury was created in order to help curb anthropogenic releases of mercury into the environment. To help achieve this end, the Global Environment Facility (GEF) developed Minamata Initial Assessment (MIA) projects to prepare countries for the ratification and implementation process. A major component of these assessments is the compilation of a standardized, comprehensive national inventory identifying and quantifying sources of mercury releases.

To help guide countries through the MIA process, the United Nations Environment Programme (UNEP) created a *Toolkit for Identification and Quantification of Mercury Releases*. The inventories from 43 countries from around the world were compiled and analyzed for this report. Those countries represent a range of socio-economic backgrounds, regions, and sizes (both in population and geographic area).

As a result of this diversity, the compiled mercury emissions and releases exhibited substantial variation, both within and across groupings. The total mercury emissions and releases by country ranged from a low of 9 kg Hg yr^{-1} to a high of 353,631 kg Hg yr^{-1}. Similarly, estimated per capita mercury emissions and releases ranged from 8 to 3,723 kg Hg yr^{-1} 100,000 $people^{-1}$. The relative contribution of each of the source categories also varied widely, with gold mining in one country contributing more than 22% of the total mercury outputs in all 43 countries combined. Consequently, the primary (virgin) metal production sector contributed the most cumulative total mercury emissions and releases. The second most emissions and releases were attributed to consumer products with intentional use of mercury (whole life cycle), while waste deposition/landfilling and waste water treatment were the third highest contributor.

The analysis of these 43 countries largely tracks with global and regional trends reported in the *Global Mercury Assessment 2018* (GMA 2018; UNEP, 2019*a*). In particular, the contribution of the artisanal and small-scale gold sector to global mercury was significant. However, it appears that these 43 countries considerably underrepresent the emissions from the extraction and use of fuels and other energy sources relative to the estimates reported in the GMA 2018. This discrepancy is likely driven by a relative lack of developed countries and the high representation rate of Small Island Developing States (SIDS) in the dataset.

The ubiquitous use of mercury-added products, reported in all 43 countries, indicates that there is substantial effort required to meet the target of phasing out these products by the end of 2020 for all parties that did not request exemptions.

The choice of *Toolkit* Level and version leads to discrepancies between inventory characteristics. Although these differences were accounted for, where possible, or noted in this report, it is important to maintain awareness of them to maximize the usefulness of these inventories as a baseline. Even accounting for these differences, the variation in mercury inventory summaries between countries in this pilot study underscores the importance of compiling additional inventories for future studies. This continued work will be vital to increasing our understanding of patterns and processes inherit in the global mercury cycle, and will help with continued efforts to protect human health and the environment from mercury, as stipulated in the objective of the Minamata Convention on Mercury (UNEP, 2017*a*).

Contents

1.0. Introduction

Mercury is a ubiquitous, persistent pollutant of global concern. Although it is naturally released into the environment through geogenic processes (e.g., volcanoes), direct and indirect anthropogenic releases far exceed natural releases. It is estimated that anthropogenic activities have cumulatively increased atmospheric concentrations of mercury by 300-500% in the past century (UNEP, 2019*a*). In addition to atmospheric emissions, mercury is directly released into land and water. Once in the environment, its transport and fate are complex as it enters a cycle moving between various media (e.g., air, water, soils, biota, etc.) with legacy mercury continuing to cycle for decades to centuries (Amos et al., 2013; Obrist et al., 2018).

As it cycles, inorganic mercury can be transformed into methylmercury by complex microbial processes (Podar et al., 2015). Methylmercury is a more readily bioavailable form of mercury that bioaccumulates in individual organisms and biomagnifies up through the food web, especially in aquatic systems (Weiner et al., 2003). Methylmercury is a potent neurotoxin that impairs physiological and neurological functioning and causes reproductive harm (Evers, 2018). Due to its global atmospheric transport, methylmercury has been documented in wildlife both in close proximity to and distant from point sources (Driscoll et al., 2013). Human exposure to methylmercury occurs most often through diet, and is known to cause adverse health effects particularly to young children and developing fetuses (Sunderland, 2007; Basu et al., 2018).

Despite its known harmful impacts on human and ecosystem health and functioning, mercury continues to be used intentionally in many products and processes (e.g., battery production), and is a byproduct of other processes (e.g., burning coal for energy generation). Atmospheric emissions are estimated to have increased by 20% from 2010 to 2015, with small reductions in Europe and North America offset by increases in other areas, particularly in Asia. Emissions from fossil fuel combustion at power plants and incinerators contribute a large proportion of atmospheric releases. Stationary coal combustion alone accounts for 21% of estimated global emissions (UNEP, 2019*a*). Additionally, mercury has long been used in the production of gold, first used by Roman smiths and then more widely adopted for mining alluvial gold deposits in the Middle Ages (Nriagu, 1994). Currently, artisanal and small-scale gold mining (ASGM) is the largest source of anthropogenic mercury emissions to the atmosphere (38% of total; UNEP, 2019*a*). Although comparatively smaller in quantity, mercury is also still used in the production of consumer products (e.g., skin lightening creams, batteries, fluorescent lamps, dental amalgams, etc.), and in some religious practices. Finally, legacy mercury remobilizes back into the environment from contaminated sites, such as landfills (Kocman et al., 2013).

Once released, mercury can be transported globally and its harmful effects experienced across international boundaries (e.g., Driscoll et al., 2013; Scheuhammer et al., 2011). To address these concerns, the United Nations Environment Programme developed a legally-binding global treaty to curb mercury releases and emissions. The Minamata Convention on Mercury was signed in October 2013 and entered into force on August 16, 2017. The Minamata Convention aims to "protect human health and the environment from the anthropogenic emissions and releases of mercury and mercury compounds" as stated in Article 1 (UNEP, 2017*a*). The Minamata Convention specifically addresses the use of mercury by the signatory countries in order to systematically control emissions and releases addressing the whole life-cycle from production and use to storage and disposal.

To help guide countries through the ratification and implementation of the Minamata Convention, Minamata Initial Assessments (MIAs) were developed as a preliminary assessment of mercury management. One component of the MIA is a National Mercury Profile; countries can develop this Profile with the aid of UNEP's *Toolkit for Identification and Quantification of Mercury Releases* (hereafter referred to as the *Toolkit*; UNEP, 2019*b*). The product of this *Toolkit* is a national mercury inventory, which approximates the magnitude and distribution of anthropogenic emissions and releases of mercury from various sectors within the country.

These mercury inventories provide valuable baseline data as the Minamata Convention requires phasing out the use of mercury in many processes and products in the future. Due to the complexity of the mercury life-cycle and issues with legacy mercury, evaluation of the effectiveness of the Convention, as required in Article 22, is complex and requires the use of multiple metrics (Evers et al., 2016; UNEP, 2017*a*). These inventories provide one such constructive metric when maintained and updated through time (Evers et al., 2016).

This pilot study examines and summarizes national mercury inventories of 43 countries that have completed the MIA process. The study was designed to inform on the relative contributions of sectors (represented by ten primary source categories included in the *Toolkit*) to mercury emissions and releases, within a set of countries representing varied global regions and socio-economic backgrounds. This baseline knowledge will help inform governments and other stakeholders with implementation of the Minamata Convention on Mercury in countries worldwide.

2.0. Results and Analysis

2.1. Country background

In total, inventories conducted in 43 countries from across the globe were included in this study (Figure 1). These countries varied widely in location, size, and socio-economic characteristics (Table 1). Of the 43 countries, seven are from Europe and Central Asia, 14 from Latin America and the Caribbean, three from the greater Asia-Pacific, and 19 from Sub-Saharan Africa. Geographic size (land area) ranges from 260 to 1,943,950 km^2, and populations range from

55,000 to 127.5 million people. According to the World Bank (2019), four countries are considered high income, 18 are upper middle income, six are lower middle income, and 15 are low income. Additionally, 15 Small Island Developing States (SIDS) are included in the study. This recognized group of countries share similar development challenges, and, generally, are small, remote, and characterized by limited resources.

***In the summaries and analyses presented below, countries are not referred to by name, but rather by a randomly assigned Country ID (1-43) in order to preserve anonymity regarding mercury inventory data*.**

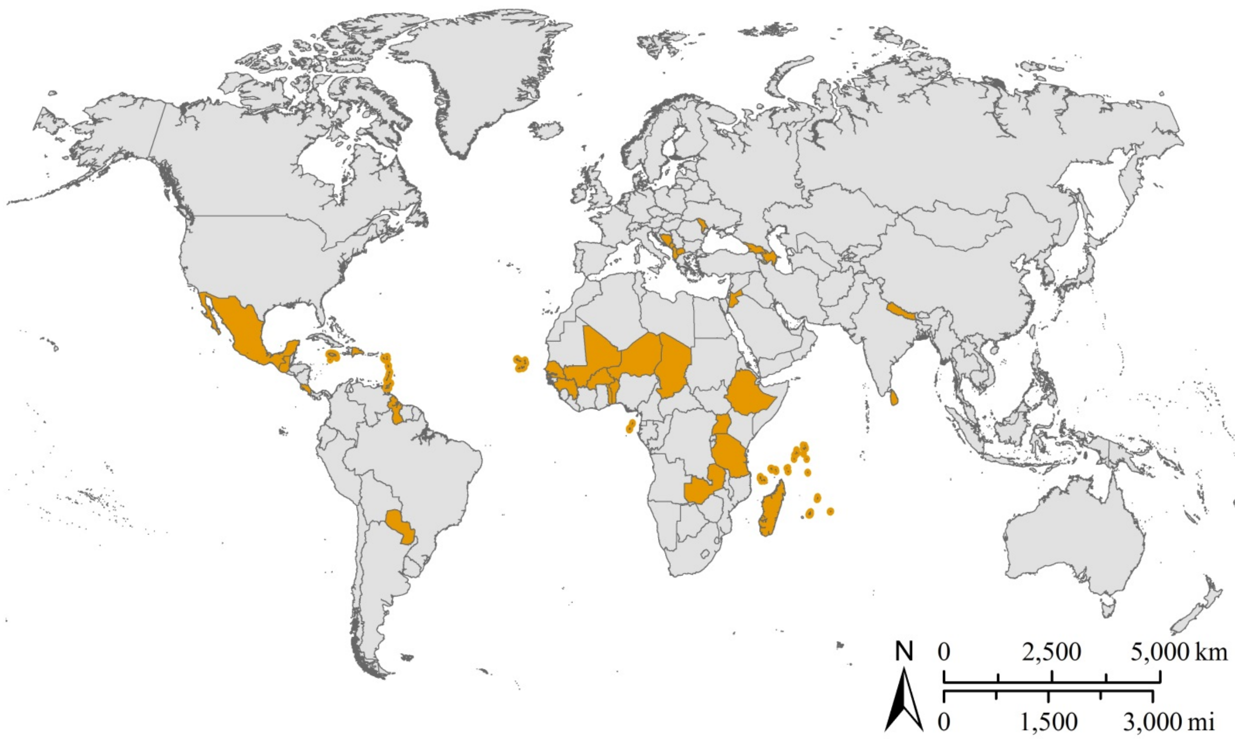

Figure 1. Inventories for the countries highlighted in orange were included in this study.

Table 1. Background information on the 43 countries included in this study.

Country	Income Group[1]	Region[1]	SIDS[2]	2016 Population[1]
Albania	Upper middle income	Europe & Central Asia	No	2,876,101
Antigua and Barbuda	High income	Latin America & Caribbean	Yes	100,963
Azerbaijan	Upper middle income	Europe & Central Asia	No	9,762,274
Benin	Low income	Sub-Saharan Africa	No	10,872,298
Bosnia and Herzegovina	Upper middle income	Europe & Central Asia	No	3,516,816
Burkina Faso	Low income	Sub-Saharan Africa	No	18,646,433
Cabo Verde	Lower middle income	Sub-Saharan Africa	Yes	539,560
Chad	Low income	Sub-Saharan Africa	No	14,452,543
Comoros	Low income	Sub-Saharan Africa	Yes	795,601
Costa Rica	Upper middle income	Latin America & Caribbean	No	4,857,274
Dominica	Upper middle income	Latin America & Caribbean	Yes	73,543
Dominican Republic	Upper middle income	Latin America & Caribbean	Yes	10,648,791
Ethiopia	Low income	Sub-Saharan Africa	No	102,403,196
Georgia	Lower middle income	Europe & Central Asia	No	3,719,300
Grenada	Upper middle income	Latin America & Caribbean	Yes	107,317
Guatemala	Upper middle income	Latin America & Caribbean	No	16,582,469
Guinea	Low income	Sub-Saharan Africa	No	12,395,924
Guyana	Upper middle income	Latin America & Caribbean	Yes	773,303
Jamaica	Upper middle income	Latin America & Caribbean	Yes	2,881,355
Jordan	Upper middle income	Asia-Pacific	No	9,455,802
Madagascar	Low income	Sub-Saharan Africa	No	24,894,551
Mali	Low income	Sub-Saharan Africa	No	17,994,837
Mauritius	Upper middle income	Sub-Saharan Africa	Yes	1,263,473
Mexico	Upper middle income	Latin America & Caribbean	No	127,540,423
Moldova	Lower middle income	Europe & Central Asia	No	3,552,000
Montenegro	Upper middle income	Europe & Central Asia	No	622,781
Nepal	Low income	Asia-Pacific	No	28,982,771
Niger	Low income	Sub-Saharan Africa	No	20,672,987
North Macedonia	Upper middle income	Europe & Central Asia	No	2,081,206
Paraguay	Upper middle income	Latin America & Caribbean	No	6,725,308
Sao Tome and Principe	Lower middle income	Sub-Saharan Africa	Yes	199,910
Senegal	Low income	Sub-Saharan Africa	No	15,411,614
Seychelles	High income	Sub-Saharan Africa	Yes	94,677
Sri Lanka	Lower middle income	Asia-Pacific	No	21,203,000
St. Kitts and Nevis	High income	Latin America & Caribbean	Yes	54,821
St. Lucia	Upper middle income	Latin America & Caribbean	Yes	178,015
St. Vincent and the Grenadines	Upper middle income	Latin America & Caribbean	Yes	109,643
Tanzania	Low income	Sub-Saharan Africa	No	55,572,201
The Gambia	Low income	Sub-Saharan Africa	No	2,038,501
Togo	Low income	Sub-Saharan Africa	No	7,606,374
Trinidad and Tobago	High income	Latin America & Caribbean	Yes	1,364,962
Uganda	Low income	Sub-Saharan Africa	No	41,487,965
Zambia	Lower middle income	Sub-Saharan Africa	No	16,591,390

[1]Category data from World Development Indicators database, combining South Asia and Middle East/North Africa regions (World Bank, 2019).
[2]Category data are extracted from UN-OHRLLS (UN-OHRLLS, 2011).

2.2. Inventories

The *Toolkit* serves as a standardized inventory quantifying emissions and releases by source. The *Toolkit* is designed using the mass-balance principle. This principle holds that the amount of mercury that is introduced into the system, or the inputs, will eventually exit the system in the form of emissions or releases. UNEP provides two versions (Level 1 and 2) of the *Toolkit* as a way to assist countries in taking stock of mercury releases. For the framework of this analysis, the primary sources categories derived in the Level 2 inventories were reported (Table 2). Level 1 inventory categories were mapped onto these Level 2 categories (Table A1). The *Toolkit* is designed to be relatively simple in its baseline requirements and then to be adaptive by allowing for further specification and customization of data. To facilitate the completion of these inventories, many of the calculations have been automated by using default input (mercury concentration in input material) and output distribution (distribution of emissions or releases between relevant release pathways) factors. As a result, only the more readily available amount of mercury-containing material, known as the activity rate, is needed. Level 2 inventories are more comprehensive, allowing further customization of factors to better reflect national data, but require more time and effort to complete.

Table 2. Level 2 Source Categories (see Appendix Table A1 for Level 1 inventory methodology).

Category	**Level 2 Source Category**
5.1	Extraction and use of fuels/energy sources
5.2	Primary (virgin) metal production
5.3	Production of other minerals and materials with mercury impurities
5.4	Intentional use of mercury in industrial processes
5.5	Consumer products with intentional use of mercury (whole life cycle)
5.6	Other intentional product/process use
5.7	Production of recycled metals
5.8	Waste incineration and burning
5.9	Waste deposition/landfilling and waste water treatment
5.10	Crematoria and cemeteries

Additionally, the *Toolkit* recognizes that waste categories (e.g., waste incineration, waste deposition, and informal dumping) risk double counting mercury. However, there remains some amount of mercury input not accounted for in the previous sectors, particularly in high volume products that only contain a small amount of mercury and are not specifically listed in the inventory (e.g., plastic products). As a result, 10% of the mercury in these waste categories are included in country totals. Unless otherwise noted, the statistics in this report are adjusted to reflect this discount.

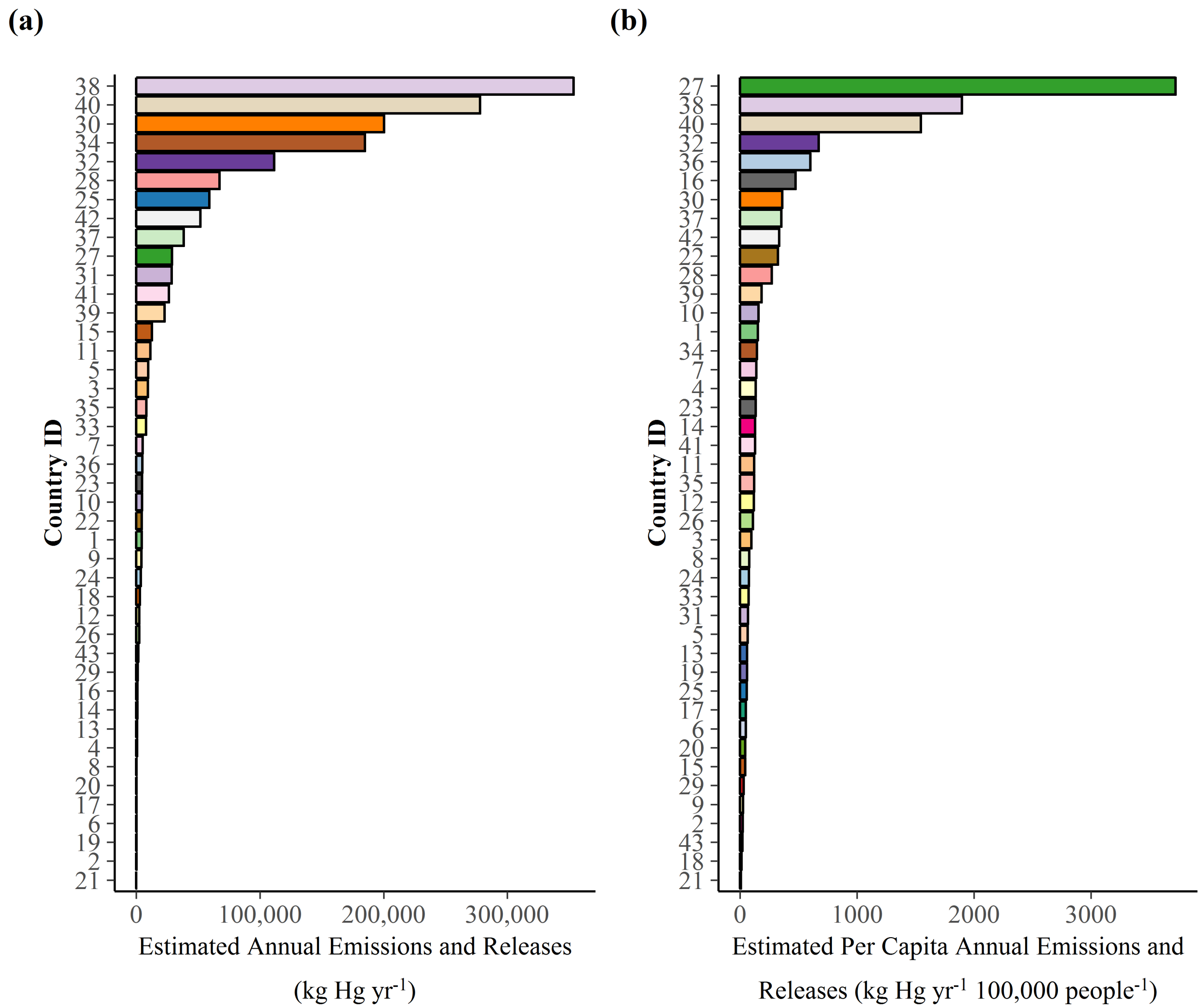

Figure 2. The estimated annual output of mercury as **(a)** total kg Hg yr^{-1} and as **(b)** total kg Hg yr^{-1} 100,000 $people^{-1}$. Countries have been randomly assigned Country IDs (1-43) in order to preserve anonymity regarding mercury inventory data. The bar colors are consistent by country.

Overall, there was substantial variation in annual mercury outputs between these countries (Figure 2). The total mercury output by country ranged from a low of 9 kg Hg yr^{-1} to a high of 353,590 kg Hg yr^{-1}. Similarly, estimated per capita mercury output ranged from 8 to 3,723 kg Hg yr^{-1} 100,000 $people^{-1}$.

Additionally, the cumulative and relative contribution of each of the 10 primary source categories to the total mercury output varied considerably by country (Figure 3, Appendix 1). Individual source categories ranged from 0 to 348,034 kg Hg yr^{-1}. The three categories that contributed the most cumulative mercury output—after discounting to avoid double counting—

were primary (virgin) metal production (5.2.), consumer products with intentional use of mercury (whole life cycle; 5.5.), and waste deposition/landfilling and waste water treatment (5.9.). On the other end of the spectrum, the categories that contributed the least were crematoria and cemeteries (5.10.)[1], intentional use of mercury in industrial processes (5.4.), and, finally, production of recycled metals (5.7.).

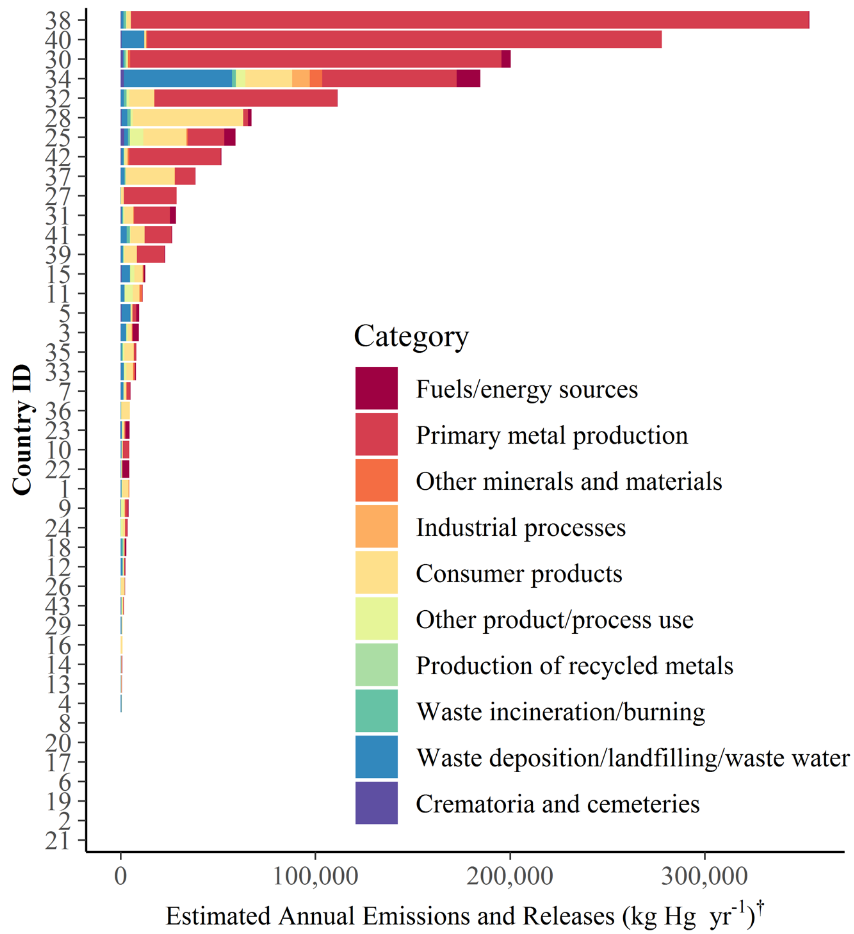

Figure 3. The estimated annual output of mercury (kg Hg yr^{-1}) from each of the source categories (as defined in Table 2) split by each of the 43 countries included in the analysis. Countries have been randomly assigned Country IDs (1-43) in order to preserve anonymity regarding mercury inventory data. †Due to overlap between source categories, some categories were adjusted according to rules in the *Toolkit* in order to avoid double-counting. The estimated annual output of mercury (kg Hg yr^{-1}) from each of the source categories by country prior to adjustment can be found in Appendix Figure B2.

It is important to note that the relative contribution values presented above and throughout this report represent data that have been corrected according to the *Toolkit* rules for avoiding double counting between categories, unless otherwise noted (see Appendix A for further details).

[1] Crematoria and cemeteries are not original sources of mercury, but are primarily a release pathway for dental amalgams.

2.2.1. Extraction and use of fuels/energy sources (5.1.)

Table 3. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from the extraction and use of fuels/energy sources. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Extraction and use of fuels/energy sources (3% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.1.1	Coal combustion in power plants	12%	6/11
5.1.2.1	Coal combustion in coal fired industrial boilers	0%	4/5
5.1.2.2	Other coal use	3%	2/19
5.1.3	Mineral oils - extraction, refining and use	3%	5/43
5.1.4	Natural gas - extraction, refining and use	34%	2/15
5.1.5	Other fossil fuels - extraction and use	0%	0/2
5.1.6	Biomass fired power and heat production	48%	2/37
5.1.7	Geothermal power production	0%	0/3

Countries classified as Small-Island Developing States (SIDS) are generally small, remote, and relatively resource poor. As a result, their mercury output from the extraction and use of fuels or energy sources is relatively low due to the difficultly and expense of relying on imported fossil fuels for energy. SIDS contributed only 9.6% of the cumulative annual mercury output from the extraction and use of fuels or energy sources, with the other 90.4% coming from the remaining countries. The mercury output from the burning of coal is even lower in SIDS (193 kg Hg yr^{-1}), representing less than 3% of the total.

Five of the 43 countries had population-adjusted mercury outputs from extraction and use of fuels/energy sources above 10 kg Hg yr^{-1} 100,000 $people^{-1}$. The three top countries in coal use on a per capita basis, all upper middle income Eastern European countries, were included in these five countries with the highest population-adjusted mercury outputs from the fuel/energy sector. In the other two countries, the high mercury output was driven by resource extraction, with over 90% of population-adjusted mercury output attributed to extraction and refining of natural gas. Of these other two countries, Country 22, had by far the highest population-adjusted mercury output at 268 kg Hg yr^{-1} 100,000 $people^{-1}$. This high income country is unique as a SIDS due to this ability to use the extraction and refining of natural gas as a resource base, which accounts for over 99% of the mercury attributed to this category in this country, and accounts for 88% of mercury outputs in SIDS countries combined.

Most of the mercury output from biomass-fired power and heat production (85.9%) was clustered in the 14 low-income Sub-Saharan African countries; these countries account for over 98.9% of the mercury from charcoal combustion reported in the inventories included in this project. These countries emitted an average of 2 kg Hg yr^{-1} 100,000 $people^{-1}$, while the remaining 29 countries averaged 0.1 kg Hg yr^{-1} 100,000 $people^{-1}$.

2.2.2. Primary (virgin) metal production (5.2.)

Table 4. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from primary (virgin) metal production. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Primary (virgin) metal production (72% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.2.1	Mercury (primary) extraction and initial processing	2%	0/1
5.2.2	Gold (and silver) extraction with mercury amalgamation processes	19%	4/14
5.2.3	Zinc extraction and initial processing	0%	2/3
5.2.4	Copper extraction and initial processing	7%	2/5
5.2.5	Lead extraction and initial processing	0%	0/1
5.2.6	Gold extraction and initial processing by methods other than mercury amalgamation	73%	2/17
5.2.7	Aluminium extraction and initial processing	0%	1/3
5.2.8	Other non-ferrous metals - extraction and processing	0%	1/1
5.2.9	Primary ferrous metal production	0%	2/7

Primary (virgin) metal production was by far the greatest contributor of mercury outputs by both cumulative and per capita measures (Figure 4), despite the fact that 19 of the 43 countries reported zero kg Hg yr^{-1} in this category. This large total output was driven by several countries with large amounts of mercury from metal production, with one country (Country 38) reporting almost 350,000 kg Hg yr^{-1} (30.8% of total output from metal production). The three countries with largest contributions in this category account for over 70% of all the mercury outputs from primary metal production.

Overall, 91.5% of the mercury from primary production of metals originated from the gold mining sector, accounting for the subcategories for both ASGM and large-scale industrial gold sources. The remaining 8.5% of this category were attributable to the production of other metals, primarily copper extraction and initial processing.

19.0% of this primary metal production category (5.2.) total was attributed to ASGM practices. However, the majority (72.6%) of the mercury emissions and releases from this category were attributed to the gold extraction and initial processing by methods other than mercury amalgamation subcategory. These mercury releases are primarily a byproduct of the industrial gold sector, which can be significant even without the deliberate use of mercury to make amalgams. As a result, countries with large gold mining industries can have high releases in this category. Countries 30, 38, and 40 account for 88.0% of the mercury in this subcategory and have extensive industrial gold mining industries resulting in the substantial mercury releases reported. However, industrial gold releases are likely overrepresented in the results. The default input factor of 15 g Hg per tonne of ore was used in 14 of the 17 countries reporting this activity. The next 2019 version of the *Toolkit* reduces that default to 5.5 g Hg per tonne of ore, a change that would substantially reduce the mercury releases attributed to industrial gold.

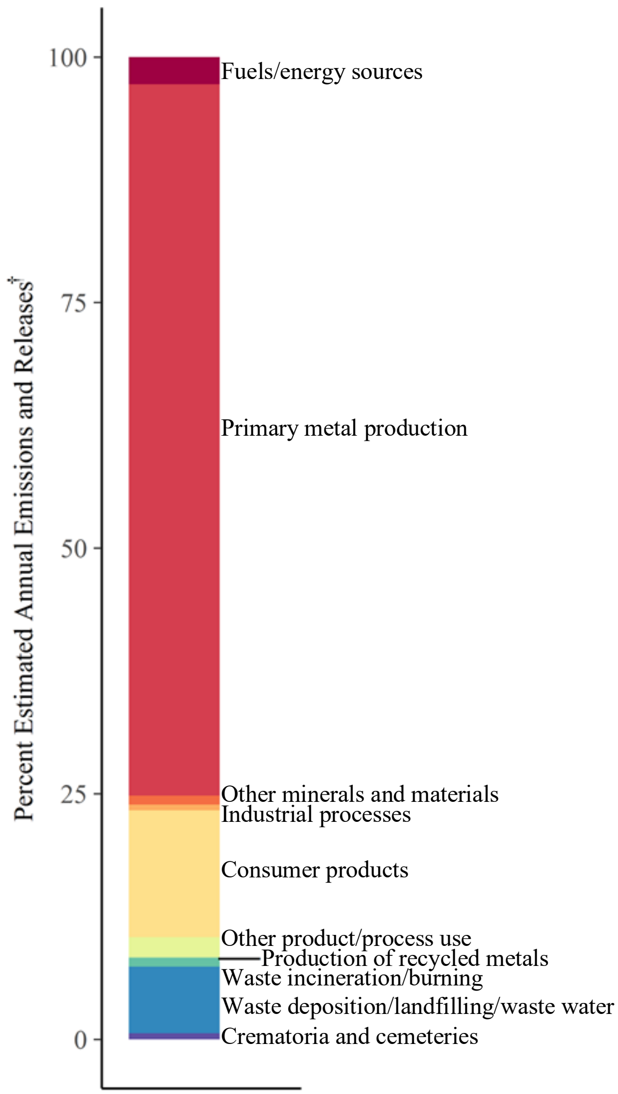

Figure 4. Estimated annual mercury emissions and releases by source category after discounting rules were applied to applicable categories.

2.2.3. Production of other minerals and materials with mercury impurities (5.3.)

Table 5. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from production of other minerals and materials with mercury impurities. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Production of other minerals and materials with mercury impurities (1% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.3.1	Cement production	100%	3/27
5.3.2	Pulp and paper production	0%	0/6
5.3.3	Production of lime and light weight aggregates	0%	7/7
5.3.4	Other minerals and materials	0%	0/0

Cumulatively, the production of other minerals and materials with mercury impurities accounted for under 1% of the reported mercury output in these countries. Almost all of this mercury (99.8%) was attributed to cement production. However, this estimate is likely an underestimate for cement production. Versions of the *Toolkit* released prior to the 2017 update (n=23) did not yet attribute the mercury resulting from burning fossil fuels in order to power cement kilns to this category. While it is difficult to retroactively account for these contributions without input from the countries because of the need to determine the proportion of the produced cement broken down by the type of fossil fuel, the underestimation is limited to the maximum relative contribution of fossil fuels to the total input when the default factors are used.

2.2.4. Intentional use of mercury in industrial processes (5.4.)

Only one country (Country 34) included mercury output from the use of mercury in an industrial process, totaling 9,093 kg Hg yr^{-1}. This output was associated with the operation of chlor-alkali plants that employ mercury technology for operation. According to the Minamata Convention, the operation of these plants is required to be phased out by 2025.

Table 6. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from intentional use of mercury in industrial processes. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Intentional use of mercury in industrial processes (3% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.4.1	Chlor-alkali production with mercury-technology	100%	1/1
5.4.2	VCM production with mercury catalyst	0%	0/0
5.4.3	Acetaldehyde production with mercury catalyst	0%	0/0
5.4.4	Other production of chemicals and polymers with mercury	0%	0/0

2.2.5. Consumer products with intentional use of mercury (whole life cycle; 5.5.)

Table 7. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from consumer products with intentional use of mercury. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Consumer products with intentional use of mercury (13% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.5.1	Thermometers with mercury	14%	3/42
5.5.2	Electrical switches and relays with mercury	19%	7/40
5.5.3	Light sources with mercury	3%	3/42
5.5.4	Batteries with mercury	32%	5/40
5.5.5	Polyurethane with mercury catalysts	4%	3/29
5.5.6	Biocides and pesticides with mercury	22%	1/1
5.5.7	Paints with mercury	1%	1/5
5.5.8	Pharmaceuticals for human and veterinary uses	0%	0/1
5.5.9	Cosmetics and related products with mercury	7%	0/14

Consumer products with the intentional use of mercury constitute 13% of the total mercury output in these 43 countries. The highest subcategory reported by an individual country (over 22% of the total for this category) was from the use and disposal of pesticides in Country 28, the only country to report mercury output in this subcategory. However, batteries were the consumer product that accounted for the highest cumulative mercury output. Specifically, over 96% of the mercury from batteries was attributed to zinc-air button cell batteries.

2.2.6. Other intentional product/process use (5.6.)

Table 8. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from other intentional product/process use. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Other intentional product/process use (2% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.6.1	Dental mercury-amalgam fillings (b	56%	6/42
5.6.2	Manometers and gauges with mercury	17%	6/43
5.6.3	Laboratory chemicals and equipment with mercury	27%	4/39
5.6.4	Mercury metal use in religious rituals and folklore medicine	0%	0/0
5.6.5	Miscellaneous product uses, mercury metal uses, and other sources	0%	0/1

Only 2% of the total mercury output in this study is attributed to this category, which covers the use of mercury in other intentional products and processes. The majority of mercury in this category was used in dental mercury-amalgam fillings. Regionally, the population adjusted mercury output (in order from lowest to highest) was as follows: Sub-Saharan Africa; Latin America and Caribbean; Europe and Central Asia; Asia-Pacific region.

The use of mercury in laboratory chemicals and equipment was the second highest subcategory accounting for slightly over a quarter of the mercury output for this category. Additionally, manometers and gauges with mercury account for 17% of this category. Mercury use for religious rituals and folklore medicine as well as other miscellaneous product uses, mercury metals uses, and other sources made up a negligible contribution to this category.

2.2.7. Production of recycled metals (5.7.)

Table 9. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from production of recycled metals. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Production of recycled metals ("secondary" metal production) (0% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of Category Total Releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.7.1	Production of recycled mercury ("secondary production")	0%	0/1
5.7.2	Production of recycled ferrous metals (iron and steel)	100%	4/17
5.7.3	Production of other recycled metals	0%	0/0

The production of recycled metals only accounted for 0.01% of the total mercury output from these 43 countries. 26 of the included countries did not report any mercury output related to this industry. More specifically, almost the entire amount of mercury output from this category was from the production of recycled ferrous metals (iron and steel). Unsurprisingly, due to their general characteristics, only 0.01% of the total mercury output attributed to this category was reported by SIDS countries.

2.2.8. Waste incineration and burning (5.8.)

Table 10. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from waste incineration and burning. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Waste incineration (1% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.8.1	Incineration of municipal/general waste	1%	1/3
5.8.2	Incineration of hazardous waste	1%	1/14
5.8.3	Incineration of medical waste	3%	3/32
5.8.4	Sewage sludge incineration	0%	0/1
5.8.5	Informal waste burning	95%	8/32

The waste incineration category captured 137,210 Kg Hg yr^{-1}, primarily from the informal waste burning subcategory (95.3% of the category total). However, the *Toolkit* recognizes that waste categories risk double counting mercury outputs (e.g., a product, such as a battery, containing mercury accounted for in the consumer products category that is then incinerated). As a result, only 10% of the total mercury in this category is counted towards a country total. After accounting for this discount, less than 1% of the total kg Hg yr^{-1} was contributed by this category.

There was also considerable variation between countries in this category. However, the average population-adjusted output from waste incineration was generally higher in lower income countries: low income countries averaged 40 ± 48, lower middle income averaged 29 ± 28, and upper middle and high income countries averaged 10 ± 21, and 10 ± 15kg Hg yr^{-1} 100,000 $people^{-1}$, respectively.

2.2.9. Waste deposition/landfilling and waste water treatment (5.9.)

Table 11. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from waste deposition/landfilling and waste water treatment. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Waste deposition/landfilling and waste water treatment (7% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.9.1	Controlled landfills/deposits (a	1%	8/36
5.9.2	Diffuse disposal under some control	0%	0/0
5.9.3	Informal local disposal of industrial production waste	0%	0/0
5.9.4	Informal dumping of general waste (b	80%	9/37
5.9.5	Waste water system/treatment	19%	6/37

The fate of waste was a major source of mercury output in these countries, with over 26% of all total mercury output coming from the waste deposition or landfilling and waste water treatment category. However, similar to the waste incineration and burning category, some of the waste covered in this category may double count mercury from other categories. As a result, only 10% of two of the five subcategories (controlled landfills and deposits and informal dumping of general waste) were counted towards the country total. After accounting for this discount, 6.8% of the total mercury output was attributed to this category.

Informal dumping of general waste contributed the largest amount of mercury output (307,317 kg Hg yr^{-1}; 80.4%). After accounting for the discount, the highest rates of mercury output from the category were found in European and Central Asian countries (28 ± 13 kg Hg yr^{-1} 100,000 $people^{-1}$), although it was highly variable between countries.

2.2.10. Crematoria and cemeteries (5.10.)

Table 12. Percentage of mercury emissions and releases from each subcategory in relation to the total emissions and releases from crematoria and cemeteries. The number of country inventories that altered at least one of the default input factors within a given subcategory is also noted.

Source category: Crematoria and cemeteries (1% of total releases)			
Subcategory	**Level 2 Source Subcategory**	**Percent of category total releases**	**Inventories with altered default input factor / total inventories reporting activity**
5.10.1	Crematoria	8%	6/18
5.10.2	Cemeteries	92%	10/40

Crematoria and cemeteries cumulatively accounted for 0.6% of the total mercury output, primarily driven by the presence of dental amalgam fillings in corpses being incinerated or buried, respectively. European countries had the highest average population-adjusted mercury output from this category (2 ± 1 kg Hg yr^{-1} 100,000 $people^{-1}$) although there was considerable variation in all regions. Asia-Pacific had the lowest output (1 ± 1 kg Hg yr^{-1} 100,000 $people^{-1}$), while Latin America and Caribbean and Sub-Saharan African countries were similar (each was 2 ± 1 kg Hg yr^{-1} 100,000 $people^{-1}$).

3.0. Assessment and Discussion

3.1. Inventories overall

Overall, there was a considerable amount of variation in mercury outputs between countries. There was also inter- and intragroup variation between countries when aggregated by economic status, SIDS categorization, or region (Figure 5). Depending on characteristics of the source, these mercury outputs are ultimately released as outputs to air, water, and/or land in varying amounts.

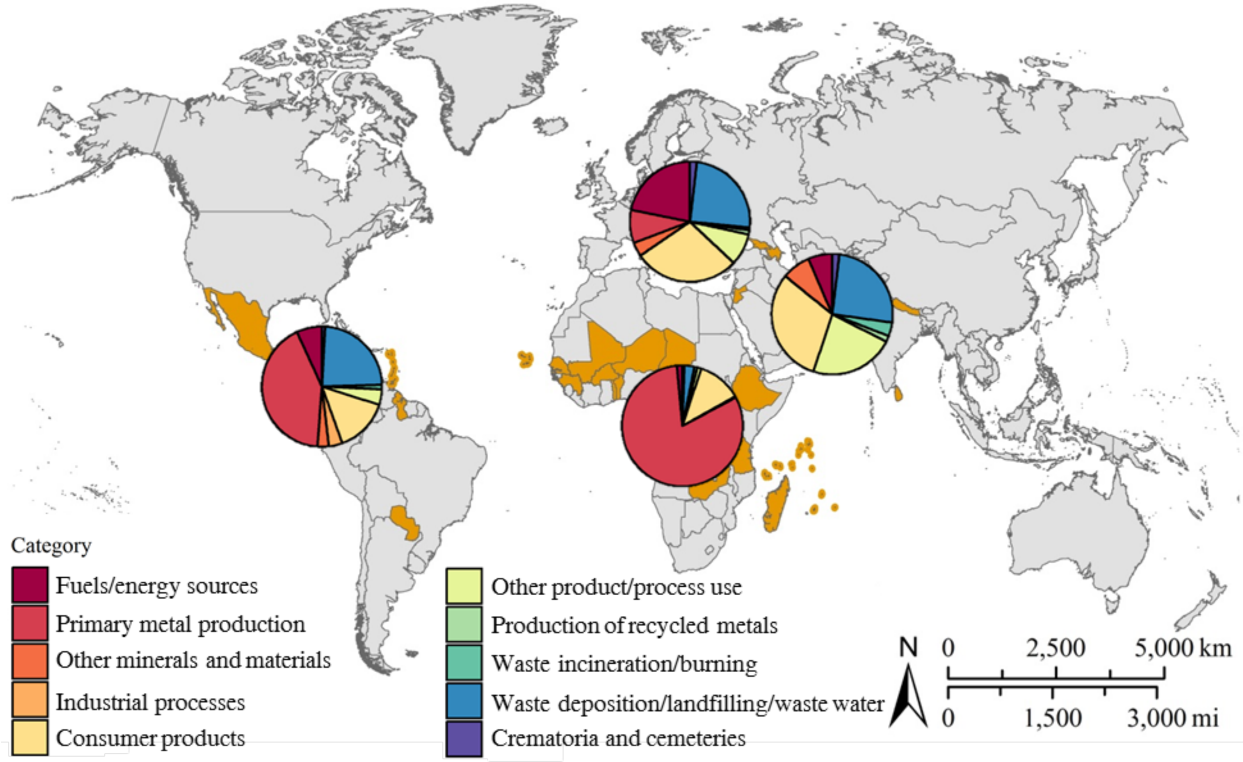

Figure 5. The estimated annual output of mercury from each of the source categories (as defined in Table 2) split by each of the 4 regions represented in the analysis.

3.1.1. Main sources of emissions to air

Emissions to the air, including both point and nonpoint sources, totaled 431,768 kg Hg yr^{-1} as reported in these 43 countries. The source category contributing the most emissions to the atmosphere was primary metal production (Table 13). These air emissions were driven by ASGM activities. ASGM techniques often involve burning mercury-gold amalgam, which releases the mercury into the air. Almost 25% of the total atmospheric emissions was attributable to ASGM activity alone. Specifically, ASGM accounts for more than three times the emissions in comparison to the industrial gold processing techniques.

This 3:1 mercury emissions ratio is the reverse of the ratio between ASGM and industrial gold in regards to total mercury outputs to society, a ratio in which mercury output from industrial gold is 3.8 times higher than from ASGM. The ratio is reversed because mercury attributed to industrial gold processes is primarily released to land.

Table 13. The proportion of atmospheric emissions and water and land release by source category.

	Source category % of emissions and releases by output compartment		
Source Category	**Air**	**Water**	**Land**
Fuels/energy sources	7	2	0
Primary metal production	36	55	95
Other minerals and materials	2	0	0
Industrial processes	0	0	0
Consumer products	16	21	5
Other product/process use	0	9	0
Production of recycled metals	0	0	0
Waste incineration/burning	31	1	0
Waste deposition/landfilling/waste water	8	21	0
Crematoria and cemeteries	0	0	1

Waste incineration and burning contributed the second highest emissions to air at 134,401 kg Hg yr^{-1} or 24 kg Hg yr^{-1} 100,000 $people^{-1}$. This waste incineration statistic is reported before the 10% discount to avoid double counting. In this specific case, it is important to understand the scale of the emissions before the discount is applied, which can help prioritize where future interventions in a product life cycle can be most effective. Additionally, the *Toolkit* rules do not apply the discount when totaling only atmospheric emissions, but the rules do apply the discount to the total emissions and releases for a country.

This output is driven primarily by informal waste burning, particularly in Sub-Saharan Africa. The Sub-Saharan African countries (n=19) averaged 37 ± 44 kg Hg yr^{-1} 100,000 $people^{-1}$ compared to Asia-Pacific (the second highest region; n=3) where the average was 15 ± 21 kg Hg yr^{-1} 100,000 $people^{-1}$.

Consumer products with intentional use of mercury contributed the third highest mercury output to air at 66,931 kg Hg yr^{-1}. The majority (52%) of this mercury output to air originated in the use and disposal of pesticides in Country 28. A further 25% came from the disposal of batteries.

3.1.2. Main sources of releases to land and water

Mercury outputs can also come in the form of more direct releases to land (including ground water) and water (water bodies including rivers, lakes, and oceans). The terrestrial environment received the largest amount of the mercury releases, with these 43 countries releasing 850,322 kg Hg yr^{-1}, almost double the emissions to the air. Meanwhile, water received the lowest output of these three environmental compartments at only 143,805 kg Hg yr^{-1}.

Primary metal extraction was also the largest source of mercury deposited into both terrestrial and aquatic systems. The releases of mercury in industrial gold processes are the largest subcategory in terms of total mercury inputs to all compartments in any of the categories. Ninety percent of the mercury released by activities in the industrial gold sector is distributed to land, compared to only 4% to air and 2% to water. As a result of this distribution, the mercury output to water follows a similar pattern to air. ASGM outputs to water are more than three times higher than the industrial gold sector despite industrial gold accounting for a higher total mercury input.

Waste deposition/landfilling and waste water treatment accounted for the second largest input of mercury to water, even after removing the contribution from waste water treatment to avoid double counting, as described in the *Toolkit* instructions. The remaining mercury output to water from this category was almost entirely (99.9%) from the informal dumping of general waste. As with the air compartment, the third largest mercury output was from consumer products with intentional use of mercury. However, while the primary sources of air emissions in this category were pesticides and batteries, almost half (49.4%) of the output to water was from the use and disposal of skin lightening creams and soaps.

As for the terrestrial compartment, consumer products with the intentional use of mercury contributed the second highest amount of mercury to land (kg Hg yr^{-1}). The biggest contributor of releases to land from consumer products was the disposal of batteries at 16,462 kg Hg yr^{-1} followed by electrical switches and relays with mercury at 9,584 kg Hg yr^{-1}. The mercury output from this category was stratified by both income and region: low and lower middle income had higher average population adjusted rates at 19 ± 37 and 24 ± 43, respectively, compared to 7 ± 12 and 1 ± 0.3 kg Hg yr^{-1} 100,000 $people^{-1}$ for upper middle and high income countries, respectively. Sub-Saharan Africa had higher average population adjusted rates of mercury deposited in terrestrial systems at 22 ± 39 kg Hg yr^{-1} 100,000 $people^{-1}$ compared the second highest region, Europe, that averaged 7 ± 9 kg Hg yr^{-1} 100,000 $people^{-1}$.

Crematoria and cemeteries was the third highest category for mercury deposition in terrestrial systems. While emissions from crematoria are exclusively to air, cemeteries release 100% of their mercury to the soil primarily from dental mercury-amalgam fillings.

3.2. Trends

3.2.1. Phasing out mercury-added products

Article 4 of the Minamata Convention on Mercury either prohibits or requires phasing down the manufacture, import, or export of certain mercury-added products after specified dates. Most products, that are not exempted, have a phase-out date of 2020 as enumerated in Annex A of the Convention (UNEP, 2017*a*). As a result, assessing the amount of mercury attributed to these products is useful for understanding the impacts of implementation of the treaty. For example, although only one country reported the continued use of pesticides containing mercury, that country contributed a total of 46,420 kg Hg yr^{-1} that will be phased out over future years.

The largest total mercury output from these products is from batteries. Unless a Party requested an exemption, the manufacture and trade of mercury-added batteries will be phased out by the end of 2020, with the exception of zinc air cells (e.g., for hearing devices) and silver oxide cells (e.g., watches) that contain less than two percent mercury. The use of mercury in batteries has been declining sharply over the last few decades. Only two of the 43 countries (Countries 9 and 42) reported the use of mercury in the manufacture of batteries (total output of 86 kg Hg yr^{-1}). The remainder of the mercury came in the form of battery use and disposal. Importantly, only 11.2% of the total calculated mercury output is attributable to zinc air and silver oxide batteries, which have explicit exceptions to the 2020 phase-out date. The phase-out of the mercury oxide and alkaline batteries will therefore eliminate more than 60,000 kg Hg yr^{-1} from these 43 countries.

The third largest contributor (after batteries and pesticides) was electrical switches and relays. Substantial progress has been made in developing mercury-free alternatives for switches leading to a decline in their manufacture; none of the inventories reported the production of switches and relays. Despite this, phase out of their use and disposal stands to reduce a cumulative 38,390 kg Hg yr^{-1}. It should be noted, however, that there are exceptions for the continued use of "very high accuracy capacitance and loss measurement bridges and high frequency radio frequency switches and relays in monitoring and control instruments with a maximum mercury content of 20 mg per bridge, switch or relay" (UNEP, 2017a). The proportion of switches and relays that would qualify for this exception remains unclear from the inventories.

The Minamata Convention also calls for the phasing down of the use of mercury in dental amalgams by providing nine measures and requiring the adaption of two or more of them. Dental amalgams are particularly important because of the multiple exposure pathways including potential risk to the person, potential risk to the dental technician, and the release of the mercury into the environment (e.g., through wastewater, in crematoria emissions, in waste disposal pathways). The mercury emissions and releases related to dental amalgams are difficult to estimate accurately due to variability in a number of factors related to the availability and standard of dental care, the size and replacement frequency of the individual amalgams, and the increasing use of mercury-free alternatives. While this synthesis only provides baseline data for each country, updating this subcategory through time will provide valuable information about the effectiveness of the measures that provide guidance on phasing down mercury in this product. Tracking this trend is particularly useful because only two countries report zero mercury output from preparations of fillings at dental clinics, which is indicative of the current mercury supply for dental amalgam fillings. Only one country reports no releases from this subcategory.

Additionally, only one country reported the use of high-efficiency amalgam filters in dental clinics, which reduces the distribution factors to water from 0.3 to 0.02.

3.2.2. Use of emissions controls for Annex D source categories

Article 8 of the Minamata Convention aims to reduce the emissions of point sources into the atmosphere. Annex D specifically addresses point source emissions of mercury (e.g., coal-fired power plants, waste incineration, etc.) at two levels. First, for all new sources covered by Annex D, the mechanism for achieving this reduction is by requiring the use of best available techniques (BATs) and best environmental practices (BEPs). Second, existing sources are covered by a different mechanism that gives them flexibility in implementing mercury emissions control measures in order to account for "national circumstances, and the economic and technical feasibility and affordability of the measures" (UNEP, 2017a).

Coal-fired power plants and industrial boilers are two types of point sources specifically listed in Annex D. The inventories partition the mercury associated with these sources into six bins depending on the level (0-5) of emission control system employed. A combination of the control system and the subtype of fuel being burned (e.g., anthracite coal) determines the amount and compartment of mercury released from these sources. Currently, the majority of coal in these countries is burned with only Level 1 controls over particulate matter, resulting in atmospheric emissions of 3,881 kg Hg yr^{-1}. Coal burned with Level 2, 3, and 4 controls released atmospheric emissions of 626, 174, and 13 kg Hg yr^{-1} respectively. The combustion of coal with no emission controls contributed 538 kg Hg yr^{-1}; currently none of the countries in this study use the highest level of mercury emission control. As a result, the implementation of better emission control techniques stands to reduce the atmospheric emissions from coal burning. It is worth noting, however, that for countries in this study the relative contribution of coal combustion is small compared to other sectors (less than 1% of total mercury outputs).

Waste incineration facilities are similarly included in requirements listed in Article 8 and Annex D of the Minamata Convention and are partitioned by mercury emission controls currently in use. Specific waste incineration sectors reported in the inventories summarized here include the incineration of municipal or general waste, hazardous waste, and medical waste. There are four emission control levels ranging from none to the use of mercury specific absorbents. Although no countries currently use the highest level of mercury emission control, 75% of the mercury in the waste was incinerated in facilities equipped with the third level of control. Fourteen percent and 11.1% of mercury in waste was incinerated in facilities with no emissions control or simple level 1 controls, respectively. However, the mercury output for incineration of waste in these facilities was dwarfed by the amount released from informal waste burning, which contributed over 95% of outputs attributed to the waste incineration category. Curtailing the informal burning of waste through a more formalized collection process has the potential to substantially reduce atmospheric mercury emissions in many of these countries.

Additionally, Annex D covers the emissions from smelting and roasting processes used in the production of nonferrous metals. The convention defines these metals as lead, zinc, copper, and industrial gold. As discussed above, the majority of the atmospheric emissions from production of nonferrous metals is from industrial gold sector. Emissions from copper processing (14,671 kg Hg yr^{-1}) were less than half of the gold sector, while emissions attributed to production of zinc and lead were 268 and 333 kg Hg yr^{-1}, respectively. While 17 countries reported emissions from the industrial gold sector, only five reported emissions from zinc, copper, or lead production.

Finally, cement production facilities are included in Annex D. These emissions totaled 9,950 kg Hg yr^{-1} for the countries included in this analysis. The majority (71%) of the mercury emissions from cement production was produced in facilities with simple particle control. A further 23.8% was produced in facilities with no mercury filters. These statistics include the 2015 version of the Level 1 inventories data divided equally between no filter and simple filter, which was the default mixed scenario. On the other hand, facilities with the three higher levels of mercury emissions controls combined to emit 5.1% of the total atmospheric emissions, while processing 7.7% of the total mercury outputs in this category.

3.3. Comparison to the Global Mercury Assessment 2018

The *Global Mercury Assessment 2018* (GMA 2018) estimates a total of 2,220 tonnes yr^{-1} of mercury emissions to the atmosphere due to anthropogenic activities (UNEP, 2019*a*). Mercury inventories from the 43 counties in this study reported a total of 431.8 tonnes of atmospheric mercury emissions annually. Analyses of the inventories in this study showed similar trends to those in the GMA 2018 for many sectors; while the results diverged in others (Table 13; UNEP, 2019*a*). However, Minamata Initial Assessments, including completion of a national inventory, are completed in developing countries and countries with economies in transition. As a result, summarization of these inventories will not perfectly align with the GMA 2018 at a global scale due to lack of representation from large, developed countries. However, the inventories enable formation of a more complete picture of mercury in countries with, generally, less information and research regarding mercury.

Table 14. Comparison of the proportion of atmospheric emissions by sector between the inventories compiled in this pilot analysis and those in the GMA 2018.

Sector	Sector % of total atmospheric emissions	
	MIA Inventories (n=43)	GMA 2018
ASGM	23.6	37.7
Biomass burning	4.8	2.3
Cement	2.3	10.5
Chlor-alkali	0.4	0.7
Coal combustion (stationary)	1.3	21.3
Cremation	0.2	0.2
Mercury Production	1.4	0.6
Industrial gold	7.6	3.8
Zinc, copper, and lead production	3.7	10.3
Waste (not incineration)	7.5	6.6
Waste incineration (controlled)	1.5	0.7

3.3.1. Gold sector

The GMA 2018 attributed a cumulative 41.5% of global emissions to the gold mining sector (including both ASGM and large-scale gold sources) and found it to be the predominant source of mercury emissions to air at a global scale. Similarly in these 43 countries, the gold sector made up 36.4% of the total mercury emissions to air. However, there are important differences between the types of gold extraction in relation to mercury output pathways. Mercury in the ASGM sector is directly used for the amalgamation process and then burned off, releasing it to the atmosphere. On the other hand, mercury releases from industrial gold are predominately a byproduct from mercury naturally present in the waste material leaching into soil or water, while mercury released to the atmosphere from this sector is primarily from preprocessing and refining operations undertaken on a small amount of the concentrated ore.

Both the GMA 2018 and results of this study show that the ASGM sector contributes notably more to global atmospheric mercury emissions than the industrial gold mining sector. Specifically, the GMA 2018 attributes 37.7% of emissions to ASGM and 3.8% to industrial gold mining (UNEP, 2019*a*), and this study attributes 23.6% and 7.6% to the two sectors respectively. This split is driven by the processes underpinning extraction of gold using ASGM compared to industrial processes. The industrial process contributes relatively little mercury to the atmosphere, with a default factor of 4% of the total mercury input (kg Hg yr^{-1}) released to the air while the vast majority (90%) of the mercury release is to land (UNEP, 2019*b*). On the other hand, ASGM releases far more of the mercury input into the air when it is burned off to separate gold from gold-mercury amalgam. More specifically, mercury output from the gold sector in this analysis are predominantly from Sub-Saharan Africa, followed by Latin America and the Caribbean (Figure 5)—a regional pattern that is also reported in the GMA 2018 (UNEP, 2019*a*).

3.3.2. Energy production

The GMA 2018 found 24% of global atmospheric mercury emissions could be attributed to stationary combustion of fossil fuels, with 21% from burning coal alone (UNEP, 2019*a*). Comparatively, this study found the proportion of mercury emissions attributed to this sector to be much lower, only 1.3% of total emissions to air. This is likely partially driven by the representation of countries included in the analysis. Fifteen of the 43 countries were SIDS, which tend to be natural resource (including coal) poor. Additionally, the countries included tend to be relatively small. The 43 countries represented here include less than 8.4% of the world population while representing approximately 22% of the world's countries. Additionally, the GMA 2018 attributes 39% of the world's total mercury emissions to East and Southeast Asia. More specifically, this region accounted for 43% of the emissions attributed to the burning of fossil fuels. Importantly, none of the corresponding countries in that region, notably China and India, are represented in this analysis.

The combustion of biomass (including domestic charcoal burning) in this study accounted for 4.8% of total atmospheric mercury emissions. Similarly, the GMA 2018 attributes 2.33% of global anthropogenic air emissions to this sector.

3.3.3. Waste deposition and landfilling

Similar proportions of global mercury emissions were attributed to waste deposition and landfilling (excluding incineration) in both the GMA 2018 and in this study (6.6% and 7.5% respectively; UNEP 2019*a*).

3.4. Level 1 and Level 2 Inventories compared

Both Level 1 and Level 2 inventories were included in this pilot project analysis. In total, there were 21 Level 1 inventories and 22 Level 2 inventories compiled. The diversity of socio-economic, demographic, and other background characteristics in countries factored into the variability of mercury emissions and releases for each Level inventory group. This intragroup variation made intergroup comparisons (Level 1 compared to Level 2) difficult to define.

The inventory levels were split, to some degree, by income level. Eleven of the 15 low income and four of the six lower middle-income inventories were Level 1. On the other hand, 12 of 18 upper middle and all four of the high income countries conducted Level 2 inventories. This split contributed to some of the differences seen in the analysis of inventory levels.

Overall, the Level 1 inventories had higher average mercury output per capita (492.8 ± 887.2 kg Hg yr^{-1} 100,000 $people^{-1}$) compared to the Level 2 inventories (133.0 ± 153.9 kg Hg yr^{-1} 100,000 $people^{-1}$). However, a large amount of this variation was driven by the extraction of primary metals, and the gold sector more specifically. For this source category specifically, Level 1 inventories averaged 356.7 ± 877.6 compared to 55.4 ± 136.1 kg Hg yr^{-1} 100,000 $people^{-1}$ for Level 2. This disparity was likely driven more by country characteristics than the inventory level selected, as most of the countries with the highest mercury output per capita for primary metal production were low income and from Sub-Saharan Africa, which had notably high rates of emissions from the gold sector.

Consumer products with the intentional use of mercury was another source category with a notable difference between Level 1 and Level 2 inventories. This disparity was primarily driven by batteries, as mercury outputs from battery use and disposal averaged 70.4 ± 148.2 kg Hg yr^{-1} 100,000 $people^{-1}$ for Level 1 inventories, compared to only 7.0 ± 14.9 for Level 2 inventories. Again, this disparity is driven by country characteristics rather than inventory level selection. It is worth noting that the top seven countries with the highest mercury output per capita specifically from mercury-oxide batteries (including a maximum of 547 kg Hg yr^{-1} 100,000 $people^{-1}$) conducted Level 1 inventories, and six are from Sub-Saharan Africa. Comparatively, the highest rate for mercury oxide batteries in Level 2 inventories was 5.8 kg Hg yr^{-1} 100,000 $people^{-1}$.

The differences between the Level 1 and Level 2 inventories that were explicitly due to different methodologies in calculating totals were accounted for where feasible in an effort to limit discrepancies attributable simply to a country's inventory level choice (Appendix A). As a result, the analysis in this report used a corrected, standardized set of values accounting for differences between the Level 1 and Level 2 reporting in summary tables.

3.5. Use for future interventions

These inventories provide a useful step for individual countries to understand the scale and distribution of their mercury emissions and releases, and allow them to evaluate the effectiveness of steps taken toward meeting requirements of the Minamata Convention on Mercury. Additionally, compilation of these inventories from multiple countries sheds light upon sectors that play a disproportionate role in the global mercury cycle. As a result, these compilations can be useful for targeting the most effective future initiatives.

First, the synthesis of mercury inventories can help to identify high-emitting sectors that are limited to specific countries or specific regions. For example, the largest atmospheric emissions in this compilation originated from ASGM activities. Mercury emissions from this sector continue to grow, primarily in developing countries throughout the tropics. Article 7 of the Minamata Convention calls for all countries where there is "more than insignificant" artisanal and small-scale gold mining to develop a National Action Plan that includes taking action to eliminate, among other things, whole ore amalgamation and open burning of amalgam or processed amalgam (UNEP, 2017*a*). First, 11 countries report the use of whole ore amalgamation processes, accounting for 29.6% of the atmospheric mercury emissions from the ASGM sector. The use of whole ore techniques is much more mercury intensive per unit of gold than the use of ore concentrates. Whole ore amalgamation requires an estimated 5 kg Hg kg gold^{-1} produced while ore concentrates require 1.3 kg Hg kg gold^{-1} produced (both assuming no retort use) according to the *Toolkit* default input factors (2017 version). Second, 98.8% of the gold extraction with mercury amalgamation processes reported in this analysis were without the use of retorts. A retort is a relatively simple device capturing mercury vapors released when burning off the mercury in the amalgam to create the sponge gold. Currently, four of the countries report the use of retorts; cumulatively accounting for only 9,982 out of 122,019 kg gold yr^{-1} produced using amalgamation processes. The further use of retorts would allow for the mercury to be recycled or, alternatively, for safe storage or disposal. The requirement in Annex C to take steps to eliminate open burning of mercury amalgam combined with the inventory data can therefore be useful for targeting safe disposal facilities and education and outreach programs on reducing the use of mercury in artisanal and small-scale gold mining.

Second, the compilation of these inventories allows for identification of sectors with high cumulative mercury totals that are widespread at a global scale. For example, battery use and disposal was reported in all but three of the 43 countries. Cumulatively, batteries contributed significantly to global mercury output, however, on a country-by-country basis, the mercury output from batteries may be overshadowed by larger sectors. As a result, inventory syntheses that identify problematic sectors or products at a global scale help to target and to prioritize solutions. This process is exemplified by the prior identification of mercury in batteries as an important issue, and the resulting requirement built into the Minamata Convention to phase out mercury in many types of batteries by 2020. As a result, nearly 90% of the mercury from batteries is scheduled to be phased out. These inventories will serve as valuable baseline tools for tracking implementation of the Minamata Convention.

3.6. Data gaps and challenges

The data used in this analysis was compiled from the *Toolkit for Identification and Quantification of Mercury Releases* completed by each of the 43 countries included in this study. The analyses, therefore, rely on the quality of the data input into these inventories. The *Toolkit* was designed to be as comprehensive an inventory of mercury inputs as possible. However, due to the complexity of the mercury cycle, it is possible that there are mercury sources that have not yet been accounted for in these inventories. Since it was originally published, the Toolkit has been updated several times to account for these deficiencies as they were identified, and this process will likely continue as knowledge improves. As a result of the continual refinement of knowledge relating to mercury, the compiled inventories using different versions of the Toolkit have variations in some calculations. There were a total of 21 Level 1 inventories and 22 Level 2 inventories. Additionally, 20 were 2017 versions, the most recent version available to the countries that have completed their inventory (Table 15). The majority of the countries completed English versions. However, there were two Spanish inventories and seven completed French versions of the *Toolkit*.

Table 15. The distribution of inventories included by Level and Version.

Level	Version	Number of Inventories
Level 1	April 2015	13
	January 2017	8
Level 2	April 2015	1
	October 2015	4
	November 2015	5
	January 2017	12

The *Toolkit* is designed to extract data primarily from easily accessible sources. Additionally, it includes default input and distribution factors. The default values are particularly important in Level 1 inventories. Both of these steps were taken to aid countries that would have difficulty obtaining these data for a variety of reasons (e.g., availability, cost, etc.). This design is advantageous for countries with fewer resources to devote to conducting the inventory. However, these defaults were necessarily developed from existing databases that tended to have been compiled in more developed countries and may not accurately reflect conditions in a specific country.

Due to the complexity of the mercury cycle, it is important to be aware of the potential for double counting the same mercury in multiple categories when examining totals. This issue is particularly important in waste categories as waste represents a substantial branch of the mercury cycle flow. For example, waste that is made up of consumer products can be accounted for in both consumer and waste sectors. However, a goal of completing the inventories is to gain knowledge on the entirety of the mercury cycle. Recognizing that the same mercury can appear in multiple sectors is important when prioritizing interventions that best minimize exposure and adverse impacts.

The *Toolkit* also provides each participating country with a baseline mercury inventory against which to evaluate future progress. This comparison over time will be particularly useful in monitoring the phase out of inputs, such as consumer products with the intentional use of mercury. However, it does not necessarily account for issues with legacy mercury that can remobilize (Amos et al., 2013). Various ecosystem or environmental characteristics (e.g., wetlands, reservoirs, etc.) also play an outsized role in determining the bioavailability of mercury (Hurley et al., 1995; Roué-Legall et al., 2005). As a result of these complex patterns and processes, the trends seen in mercury concentrations in biota may not follow a consistent pattern in mercury inputs into the environment or may experience a significant time lag.

4.0. Conclusions and Next Steps

The 43 mercury inventories completed using the *Toolkit for Identification and Quantification of Mercury Releases* provide valuable baseline information for the countries that conducted them. Compiling these inventories allows for assessment of the cumulative and relative contributions from various sectors to the global mercury budget. Notably, the use of mercury-added products was reported in all 43 countries synthesized here. While these inventories do not currently inform on trends over time, the ubiquity of these products indicates that substantial efforts are likely needed given the target to phase out their use by the end of 2020. Additionally, these inventories reinforce regional patterns reported in the *Global Mercury Assessment 2018* by providing a comprehensive inventory of mercury inputs and releases broken down by media (UNEP, 2019*a*). The synthesis was complicated by discrepancies between *Toolkit* Levels and versions. It will remain vital to be aware of and account for these differences to maximize the accuracy of using these inventories as a baseline to be updated and tracked over time. Overlaying these spatial and, eventually, temporal trends with other mercury models would allow for identification of patterns at a country, regional, and global scale, helping target and prioritize the most effective future interventions.

The 43 countries that are represented in this pilot analysis are diverse in size, region, development status, and relative income, among other factors. As a result, the mercury inventories described here reflect this diversity in the high variation of the total and per capita output, major contributing sectors, and relative proportions of source categories. This variation highlights the importance of obtaining additional inventories to include in future analyses in order to help elucidate patterns and processes, especially in areas with little or limited data. As mercury is a ubiquitous, persistent contaminant known to cause adverse health outcomes, understanding these patterns is vital to prioritizing steps to minimize human exposure and adverse impacts on ecosystem health and function, particularly in light of the requirements of the Minamata Convention on Mercury.

5.0. References

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Appendix A. Methodology

A.1. Data compilation

Article 8 of the Minamata Convention on Mercury states that "[e]ach Party shall establish, as soon as practicable and no later than five years after the date of entry into force of the Convention for it, and maintain thereafter, an inventory of emissions from relevant sources" (UNEP, 2017*a*). Pursuant to this obligation, each of the 43 countries included in this report undertook an inventory to comprehensively quantify sources of mercury emissions and releases. These inventories employed the UNEP's *Toolkit for Identification and Quantification of Mercury Releases* (UNEP, 2019*b*). However, due to sensitivity regarding the exact amounts of mercury released, each country was randomly assigned an ID number between one and 43 and those IDs were used, where appropriate, in reporting results from individual countries.

A.2. Data challenges

A.2.1. Combining Level 1 and Level 2 Inventories

UNEP provides two versions (Level 1 and 2) of the *Toolkit* as a way to assist countries in taking stock of mercury releases. Level 2 inventories are more comprehensive, allowing further customization of factors to better reflect national data, but require more time and effort to complete. UNEP has also updated the *Toolkit* multiple times since its original release. As a result, some specific categories not explicitly delineated in initial inventories (e.g., fossil fuel amounts from cement production) have been added through time. However, when exploring differences between emissions and releases from specific products and sectors between countries, care was taken to note comparisons impacted by these differences. Additionally, some default values have also been altered during updates of the *Toolkit* to reflect the improving knowledge. However, it was beyond the scope of this pilot project to recalculate inventories from individual countries. The inventories included represent the best currently available estimates for mercury emissions and releases for each country.

The Level 2 *Toolkit* separates the executive summary into 10 separate primary source categories that were used as the basis for many of the analyses in this report (Table A1). However, the Level 1 *Toolkit* the executive summary is divided into 17 source categories. 15 of these 17 categories were mapped directly onto the Level 2 source categories. The remaining two categories (Production of products with mercury content and Use and disposal of other products) were each split, using their sub-categories, between two Level 2 source categories (Consumer products with intentional use of mercury (whole life cycle) and other intentional product/process use).

The differences between the Level 1 and Level 2 inventories that were explicitly due to different methodologies in calculating totals were accounted for where feasible in an effort to limit discrepancies attributable simply to a country's inventory level choice. One of the largest initial differences between Level 1 and Level 2 inventories was related to the waste deposition and landfilling category. Specifically, the two inventories used different inputs to report the mercury input column in the total summary. For example, the Level 1 controlled landfills and deposits subcategory is reported as a simple calculation using the amount of waste landfilled and the mercury in each unit of waste as the mercury input. In Level 2 inventories, the input in the total summary table for this same subcategory is reported after applying an output distribution factor; as a result the inputs in Level 2 inventories are a cumulative account of mercury outputs. However, the sum of the output distribution factors across the output compartments is not always one. In those instances, the sum of mercury outputs in a Level 1 inventory category will not equal 100% of the mercury input. As a result, Level 1 inventories report higher mercury inputs from an equal amount of waste in these categories in comparison to Level 2 inventories. However, the discrepancy was accounted for calculating the country totals by reporting the cumulative output from all inventories (Level 2 approach).

A.2.2. Accounting for double counting due to the life-cycle approach

Similarly, some categories within the inventories overlap when considering the entire mercury cycle. As a result, adjustments were made to some categories when calculating the country-based totals in order to avoid double counting products (e.g., batteries being incinerated) or processes flowing through the cycle (e.g., dental amalgams in wastewater; UNEP, 2017*b*). However, the amount of mercury included in these categories is still important to understanding the fate and transport of mercury in the environment and in terms of prioritizing avenues for intervention.

More specifically, only 10% of the mercury input to waste incineration, waste deposition, and informal dumping were included in the country total. This discount avoids double counting some mercury inputs. For example, the incineration of a consumer product with the intentional use of mercury where the mercury was catalogued in the source category covering the production and use of the product. The incineration of that product would subsequently release that same mercury into the atmosphere. However, some amount of mercury input is not accounted for in the previous sectors. The 10% included in this category helps account for many products that are not specifically enumerated in the inventory with large quantities of waste but relatively low mercury concentrations (e.g., plastic products).

Along these lines, the output amounts to specific compartments or media in several categories were adjusted to avoid double counting. The contribution of mercury to land from informal dumping of waste was subtracted from the country total release to land. Similarly, the release to water from wastewater treatment plants was not included in the country total release to water.

Additionally, some corrections have been made to avoid double counting some products that are both produced and used in the same country. And lastly, some products and processes transcend country or year boundaries. As a result of these adjustments, the total inputs and releases will not necessarily equal each other.

A.2.3. Country Level Corrections

There are some differences noted in the calculations within several inventories that were standardized to ensure better consistency in data comparisons. These were primarily reflected in calculations of totals for individual countries total and executive summary tables. The Inventory levels differ in their treatment of waste water systems/treatment in calculating country totals due to differing uses of the term input. Specifically, Level 1 inventories subtract the mercury attributed to waste water from the input totals and the releases to water. On the other hand, the Level 2 inventories only subtract the waste water data specifically attributed as a release into water, while including it in the input total for the country. Along similar lines, older versions (2015) of the Level 2 inventory *Toolkit* did not automate charcoal combustion data into the summary tables, instead only pulling the biomass burning data. As a result, they were included where appropriate to match the methodologies of the majority of countries. It should also be noted that countries that conducted Level 1 inventories also have the option to insert Level 2 results for sectors with more detailed inventories. These results are automatically inserted into summary tables in the *Toolkits*, but not propagated through *Toolkit* spreadsheets covering the subcategory sectors.

Table A1. Comparison of Level 2 and Level 1 Source Categories.

Category	Level 2 Source Category	Level 1 Source Category
5.1	Extraction and use of fuels/energy sources	Coal combustion and other coal use
		Other fossil fuel and biomass combustion
		Oil and gas production
5.2	Primary (virgin) metal production	Primary metal production (excl. gold production by amalgamation)
		Gold extraction with mercury amalgamation
5.3	Production of other minerals and materials with mercury impurities	Other materials production
5.4	Intentional use of mercury in industrial processes	Chlor-alkali production with mercury-cells
		Other production of chemicals and polymers
5.5	Consumer products with intentional use of mercury (whole life cycle)	Production of products with mercury content[1]
		Use and disposal of other products[1]
5.6	Other intentional product/process use	Production of products with mercury content[1]
		Use and disposal of other products[1]
		Application, use and disposal of dental amalgam fillings
5.7	Production of recycled metals	Production of recycled metals
5.8	Waste incineration and burning	Waste incineration and open waste burning
5.9	Waste deposition/landfilling and waste water treatment	Waste deposition
		Informal dumping of general waste
		Waste water system/treatment
5.10	Crematoria and cemeteries	Crematoria and cemeteries

[1]Sub-categories were used to divide these Level 1 Source Categories between two Level 2 Source Categories.

Appendix B.

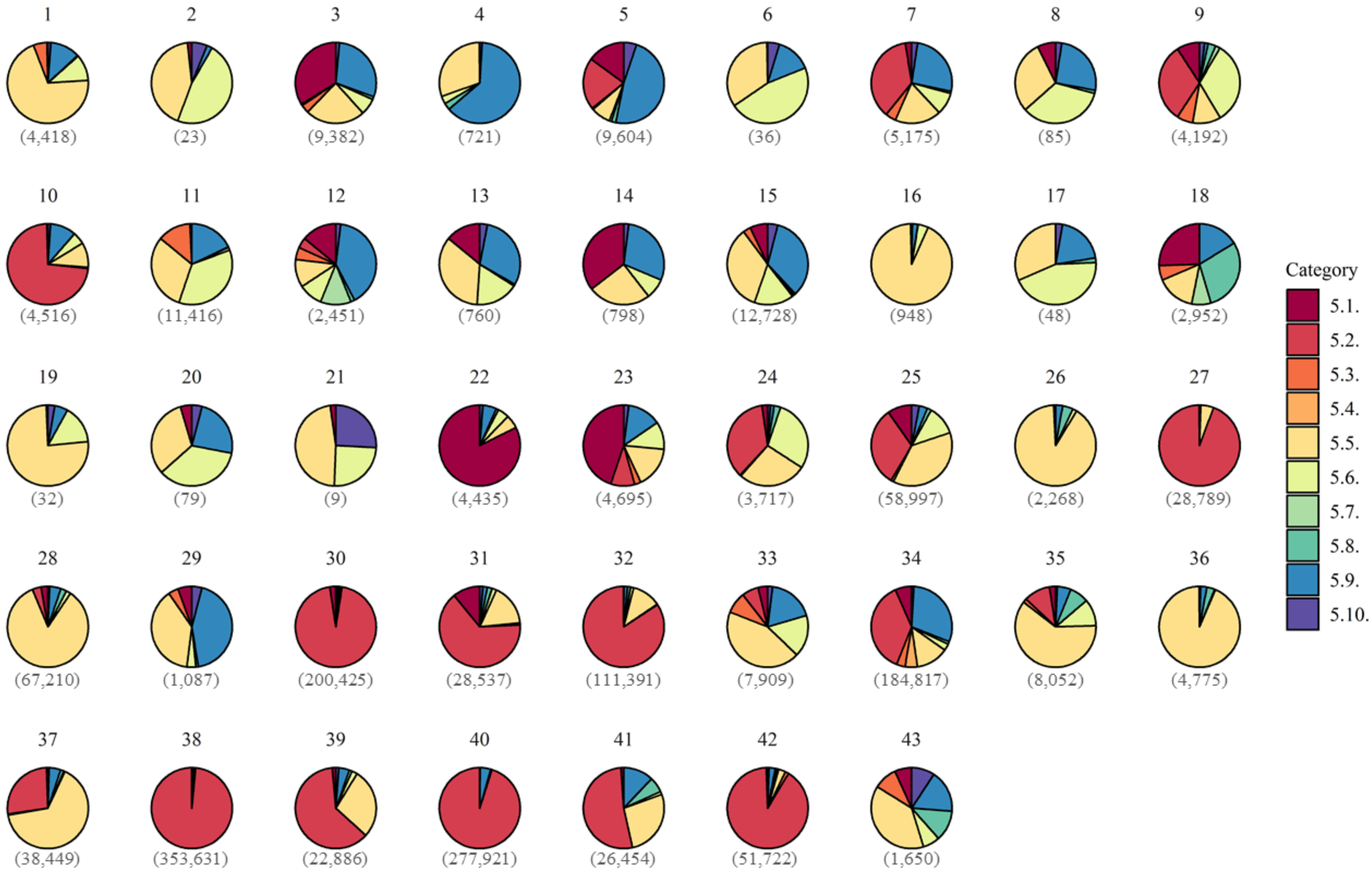

Figure B1. The proportion of mercury emissions and releases by category in each of the 43 countries in the analysis. Gray numbers beneath each pie are the total annual mercury emissions and releases (kg Hg yr^{-1}). The categories are (5.1.) Fuels/energy sources, (5.2.) Primary metal production, (5.3.) Other minerals and materials, (5.4.) Industrial processes, (5.5.) Consumer products, (5.6.) Other product/process use, (5.7.) Production of recycled metals, (5.8.) Waste incineration/burning, (5.9.) Waste deposition/landfilling/waste water, and (5.10.) Crematoria and cemeteries.

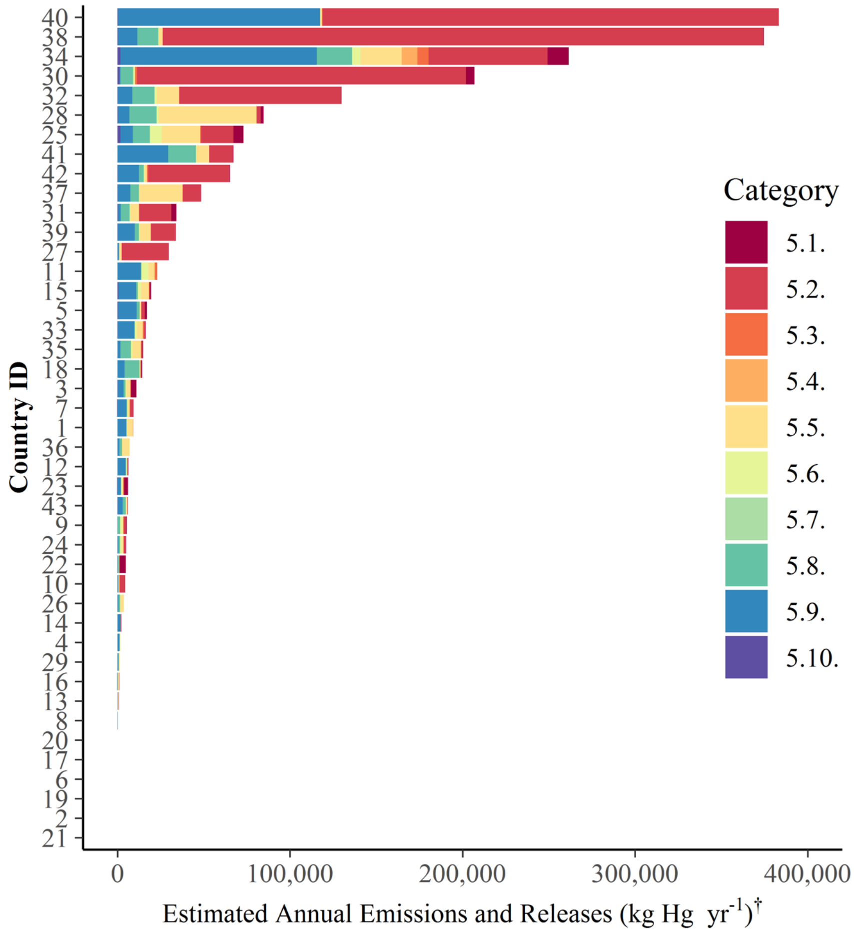

Figure B2. The estimated annual input of mercury (kg Hg yr^{-1}) from each of the source categories (as defined in Table 2) split by each of the 43 countries included in the analysis. The categories are (5.1.) Fuels/energy sources, (5.2.) Primary metal production, (5.3.) Other minerals and materials, (5.4.) Industrial processes, (5.5.) Consumer products, (5.6.) Other product/process use, (5.7.) Production of recycled metals, (5.8.) Waste incineration/burning, (5.9.) Waste deposition/landfilling/waste water, and (5.10.) Crematoria and cemeteries.

†Due to overlap between some categories, the sum of all source categories is larger than the total estimated annual input as seen in Figure 2, which accounts for this double counting.