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Abstract:

This is a joint UNEP and AMAP report that presents the latest and comprehensive information on global mercury emissions and releases to the environment, and on atmospheric and aquatic chemistry and fate and transport of mercury. The report is a fully referenced scientific background report for the Global Mercury Assessment 2013; Sources, Emissions, Releases, and Environmental Transport. Work carried out

by the Artisanal Gold Council through its grant with the IDRC contributed to the information found within this document regarding mercury use and release in the ASGM sector.

Keywords: mercury, global, emissions, estimates, methodologies

Technical Background Report for the Global Mercury Assessment 2013





AMAP

Technical Background Report for the Global Mercury Assessment 2013

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Preface

This report details the technical background to the *Global Mercury Assessment 2013 – Sources, Emissions, Releases and Environmental Transport* (summary for policy-makers) that has been developed in response to Decision 25/5 III, paragraph 36 of the Governing Council of the United Nations Environment Programme (UNEP), that: “Request the Executive Director, in consultation with Governments, to update the 2008 report entitled “*Global Atmospheric Mercury Assessment: Sources, Emissions and Transport*” for consideration by the Governing Council / Global Ministerial Environment Forum at its twenty-seventh session.”

This technical background report has been developed in collaboration with the Arctic Monitoring and Assessment Programme (AMAP). As such, this report also constitutes a contribution to the work of AMAP and the Arctic Council.

Chapter 2 of this report (*Global Emissions of Mercury to the Atmosphere*) was developed by a joint UNEP/AMAP Expert Group, building on the competence established during the AMAP/UNEP collaboration that resulted in the 2008 *Technical Background Report to the Global Atmospheric Mercury Assessment: Sources, Emissions and Transport* report (UNEP, 2008). In producing this part of the report, considerable efforts were made to engage a wide participation of national experts from regions around the globe. Thanks to funding provided by Canada, Denmark, Japan, Sweden, Norway, the Nordic Council of Ministers, and the EU, experts from Argentina, Australia, Brazil, China, India, Japan, Mexico, Republic of Korea, South Africa and the USA actively participated in the work to develop Chapter 2 of this report. Expertise and information made available through the UNEP Partnership area on Mercury Control from Coal Combustion Information was used, as were data acquired during the preparation of the UNEP Paragraph 29 study (*Study on Mercury Sources and Emissions, and Analysis of Cost and Effectiveness of Control Measures*, UNEP 2010a). The sections concerning artisanal and small-scale gold mining were developed through cooperation with experts from the UNEP Partnership on Reducing Mercury in Artisanal and Small-scale Gold Mining and from the Artisanal Gold Council (AGC).

Chapter 3 of this report (Atmospheric Pathways, Transport and Fate) was prepared by experts from the UNEP Mercury Air Transport and Fate Research Partnership Area.

Chapter 4 of this report (Global Releases of Mercury to Aquatic Environments) was prepared by a UNEP/AMAP expert group under the leadership of experts from the Institute Jožef Stefan (Slovenia) and utilised material prepared for UNEP by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP).

Chapter 5 of this report (Aquatic Pathways, Transport and Fate) was prepared by a UNEP/AMAP expert group under the

leadership of experts from the Geological Survey of Canada and the University of Connecticut and contributions from Institute Jožef Stefan (Slovenia). The input of John Munthe to this work is also greatly appreciated.

1. Introduction

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1.1 Background and mandate

In 2009, UNEP's Governing Council (GC) requested that "UNEP in consultation with Governments, update the 2008 report entitled *Global Atmospheric Mercury Assessment: Sources, Emissions and Transport* for consideration by the Governing Council/Global Ministerial Environment Forum at its twenty-seventh session in 2013". (Decision 25/5 III, paragraph 36).

Building on the 2008 report, the new report entitled *Global Mercury Assessment 2013 - Sources, Emissions, Releases and Environmental Transport* should provide updated:

(a) Best available data on mercury atmospheric emissions and trends including where possible an analysis by country, region and sector, including a consideration of factors driving such trends and applicable regulatory mechanisms; and

(b) Current results from modelling on a global scale and from other information sources on the contribution of regional emissions to deposition which may result in adverse effects and the potential benefits from reducing such emissions, taking into account the efforts of the Fate and Transport partnership established under the United Nations Environment Programme mercury programme.

The main focus of the updated report is on mercury (Hg) emissions to the air and pathways and fate of atmospheric Hg. However, in response to questions raised by several

governments in the Intergovernmental Negotiating Committee (INC) developing a global instrument on Hg to include releases to water, the content of the updated report has been expanded to include information on Hg releases to water and pathways and fate in aquatic environments.

This report (*Technical Background Report for the Global Mercury Assessment 2013*) provides the detailed technical background for the information and findings that are presented in the *Global Mercury Assessment 2013 - Sources, Emissions, Releases and Environmental Transport* summary report. It consists of five parts:

Chapter 1 – Introduction

Chapter 2 – Global Emissions of Mercury to the Atmosphere

Chapter 3 – Atmospheric Pathways, Transport and Fate

Chapter 4 – Global Releases of Mercury to Aquatic Environments

Chapter 5 – Aquatic Pathways, Transport and Fate

As described above, this report deals with Hg releases to the atmosphere and water, and the pathways and fate of Hg after it has entered the atmosphere and aquatic environments. Figure 1.1 illustrates these components, showing which parts of the global Hg cycle are considered in the various chapters of this report – Figure 1.1 can therefore be viewed as a 'road map' for the report. Figure 1.2, using the same basic diagram shows, in quantitative terms, the main features of the global Hg cycle, including numerical estimates for the Hg 'storage' and flux components that are described in more detail in the following chapters.

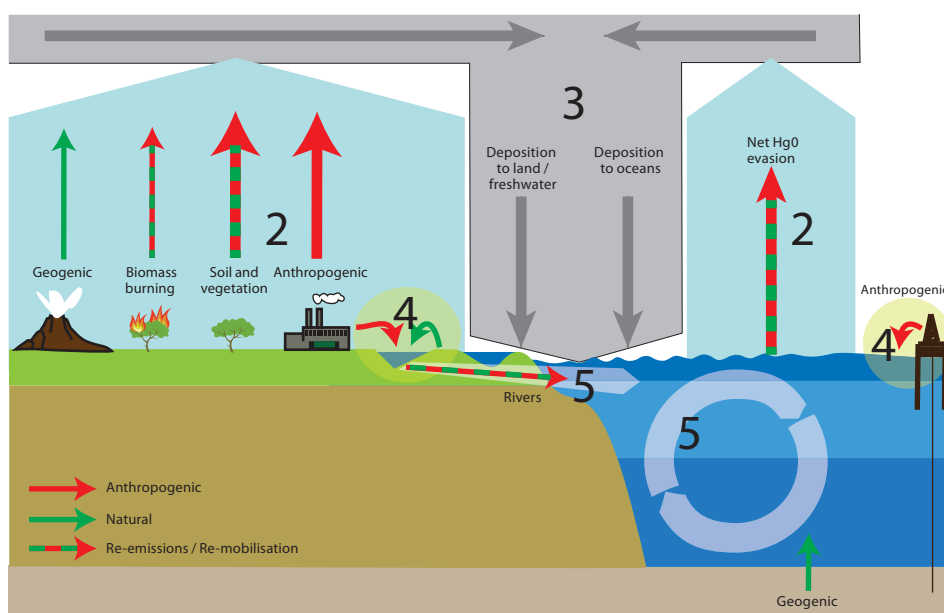


Figure 1.1. Components of the global mercury cycle as addressed in this report. Numbers refer to the chapters of this report.

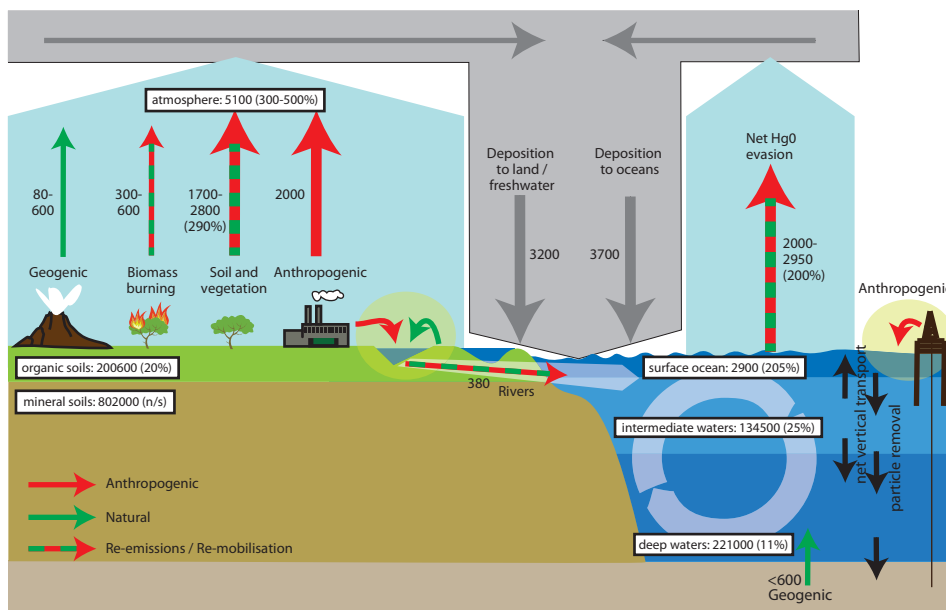


Figure 1.2. The global mercury budget. Source: adapted from Mason et al. (2012). Total inventories (numbers in white boxes) are in tonnes, and fluxes in tonnes per year. The percentage values in brackets are the estimated increases in inventories in the past 100 years due to anthropogenic activities.

1.2 Global mercury budgets

Mercury is released to the environment from natural sources and processes and as a result of human activities. Once it has entered the environment, Hg cycles between major environmental compartments – air, soils and waters – until it is eventually removed from the system through burial in deep ocean sediments and mineral soils. Methylmercury, the most toxic and bioaccumulative form of Hg which presents most health risk to humans and wildlife, is mainly produced in aquatic ecosystems through natural bacterial processes.

In order to provide a general framework for the discussions in Chapters 2 to 5 of this report, the following section presents a global Hg budget based on recent modelling work.

Owing to its scale and chemical complexity, and the lack of detailed information for many parts of the ecosystem, global-scale models provide the most practical means of describing the global Hg cycle in a quantitative manner. A number of global atmospheric Hg models exist. But until recently, only one combined atmospheric-terrestrial-oceanic model has been available, the GEOS-Chem Mercury model (Strode et al., 2007; Smith-Downey et al., 2010; Mason et al., 2012). Recent GEOS-Chem model results, as described by Mason et al. (2012), represent the current ‘best estimate’ of the global Hg budget. The model is constrained and generally supported by empirical data on Hg concentrations and fluxes in various environmental media, and represents a consensus which has not been challenged within the Hg scientific community.

As with all such modelled budgets, large uncertainties exist regarding both the amounts of Hg ‘stored’ in the different environmental compartments and the fluxes of Hg between these compartments (see Table 1.1). Most of these uncertainties are due to unknown or poorly known input parameters and process rates, as discussed in more detail in Chapter 3. Despite this fact, most global Hg models do not present uncertainty estimates on their mass balances and fluxes. Sunderland and Mason (2007)

reported that 90% confidence intervals for GEOS-Chem estimates of most fluxes (i.e., for rivers, atmospheric deposition, particle settling, lateral and vertical flows) were only 2- to 4-times as large as the median or best estimate values. However, the estimates of evasion were less certain, with 90% intervals of 5–10 times the best estimate for different ocean basins. Uncertainty analysis conducted as part of new global Hg modelling work by Qureshi et al. (2011; the World Multimedia Mercury Model, WorM3) suggested that 95% estimate dispersion ranges were over an order of magnitude for most global Hg inventories and fluxes. However, the best estimates from Qureshi et al. (2011) compared well with other models. For example, Qureshi et al. (2011) estimated a net conversion of Hg⁰ (elemental mercury) to Hg^{II} (inorganic divalent mercury) in the atmosphere of 3000 t/y, with a 95% range of 400 to 12 400 t/y. This average compares favourably with the 6000 t/y estimate using GEOS-Chem (Selin et al., 2007). The calculated atmospheric residence time of Hg⁰ in WorM3 was 8.2 months with a 95% dispersion of 2.4 to 24 months, which also agrees well with other estimates of 8.4 to 20.4 months (Holmes et al., 2006; Selin et al., 2007). In general, good agreement (within a factor of three) was observed for the best estimates of most global Hg compartment inventories, chemical reaction rates and fluxes, between WorM3 (Qureshi et al., 2011) and other spatially resolved global models including GEOS-Chem (Lamborg et al., 2002; Selin et al., 2008; Sunderland and Mason, 2007; Soerensen et al., 2010; Smith-Downey et al., 2010). The largest potential errors in the GEOS-Chem model, in the context of the aquatic Hg cycle, may concern air-water gas exchange, specifically: (i) the mechanisms of the redox reactions in surface oceans, as defined by the amount of reducible Hg present in surface oceans, and rate constants for reduction and oxidation of Hg species by various pathways; (ii) atmosphere-water Hg mass transfer processes as defined by wind velocity; and (iii) Hg species inter-conversion reactions in the atmosphere (Qureshi et al., 2011). It was estimated that these uncertainties may contribute more than errors in anthropogenic emission estimates to the total uncertainty in modelled atmospheric concentrations and deposition fluxes.

Table 1.1. Estimates of environmental mercury fluxes. Source: updated from AMAP/UNEP (2008).

Hg fluxes, t/y	Selin et al., 2007	Soerensen et al., 2010	Holmes et al., 2010b	Mason et al., 2012
Natural emissions from land to atmosphere	900		500	80–600
Natural emissions to oceans				< 600
Anthropogenic emissions	2200		2100	2000
Re-emissions from land	1500		1700	1700–2800
Emissions from biomass burning			300	300–600
Re-emissions from ocean	2400	2900	3700	2000–2900
Total sources	7000		7800	6100–8900
Deposition to land			3000	3200
Deposition to ocean		3700	5300	3700
Total deposition	7000		8300	6900

Notwithstanding these uncertainties, such budgets provide a useful framework for describing the structure of the material in this report and also for explaining the way that anthropogenic releases impact on the Hg cycle.

Total annual Hg emissions to the atmosphere have been estimated at up to 8900 t/y (see Table 1.1). The budget of Mason et al. (2012) estimates current Hg emissions to the atmosphere from natural and anthropogenic sources at about 80–600 t/y and about 2000 t/y, respectively, with re-emissions making up the remainder. The indicated anthropogenic flux value of 2000 t/y is an approximate estimate; a detailed quantification of current (2010) Hg emissions to air from anthropogenic sources is the subject of Chapter 2 of this report.

Comparing pre-industrial and post-industrial emissions from all sources, Sunderland and Mason (2007) concluded that human effects on the Hg cycle have resulted in about three-times as much Hg being emitted to the atmosphere now than in the pre-industrial period. Anthropogenic emissions increased significantly following the (European) industrial revolution around 200 years ago, and are likely to have peaked sometime in the late 20th century. As more countries experience industrial development, resource exploitation continues. However reductions in atmospheric Hg emissions have also occurred due to changes in fuel use and co-benefits from improved emission control technologies for major air pollutants (particles, sulphur oxides and nitrogen oxides) at major emission sources such as power stations and industrial plants, as well as the introduction of Hg-specific controls at some facilities and reduced use of Hg in products and some industrial processes.

Estimates of current annual emissions associated with some re-emission components have been quantified on the basis of studies involving measurements as well as models. For example, emissions from biomass burning, which includes both natural wildfires and anthropogenic (agricultural and other) biomass burning were estimated at $\sim 675 \pm 240$ t/y (Friedli et al., 2009). In the case of biomass burning, much of the Hg emitted to the atmosphere is likely to be associated with re-emission of Hg previously deposited onto vegetation surfaces, with a small fraction from Hg uptake

from soils by root systems. Similarly, fast re-emission of Hg from ice and snow following atmospheric mercury depletion events (AMDEs) has been estimated to re-emit up to 80% of the atmospheric deposition in the Arctic associated with AMDEs (AMAP, 2011). However, estimates for the most significant re-emission components – re-emissions from soils/vegetation and evasion from ocean surface waters – are derived mainly from models. Through their parameterisation of geochemical processes, these models attempt to balance budgets and residence times of Hg in various components of the geosphere, in a manner that is consistent with observed levels of Hg in different media. Oceanic re-emissions have been measured during cruises in most of the world's major oceans but these results only cover limited geographical and temporal scales and thus need to be scaled up to derive global estimates. Recent publications that present global Hg budgets based on the GEOS-Chem budget model imply annual re-emissions to air from soils and oceans of 1700–2800 and 2000–2950 t/y, respectively (Mason et al., 2012, Figure 1.2). The budget presented by Holmes et al. (2010b) has corresponding re-emission estimates of 1700 and 3700 t/y, respectively. The natural (geogenic) emissions from land (mainly volcanic emissions) are estimated to be 80–600 t/y. Natural sources also release Hg to the ocean through sub-surface vents, however this contribution (estimated at <600 t/y) is believed to be largely retained around the location of the vents and therefore only a small part of this release enters the water column.

Other types of model employed to simulate Hg atmospheric transport include somewhat lower estimates of Hg emissions to the atmosphere from natural and re-emission sources of 3500 t/y (GRAHM model, AMAP, 2011) and 4230 t/y (GLEMOS model, AMAP, 2011). Estimates of natural emissions and re-emission of Hg to the atmosphere thus are subject to considerable uncertainty. This report uses the budget numbers of Mason et al. (2012) as a basis for discussions because they are the most recent, building on previous budgets by Soerensen et al. (2010) and Holmes et al. (2010b). They are also the most comprehensive yet published in terms of coverage of Hg fluxes and inventories in different environmental compartments.

2. Global Emissions of Mercury to the Atmosphere

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2.1 Sources of mercury emissions to the atmosphere

2.1.1 Natural, anthropogenic and re-emission source categories

As discussed in the 2008 *Global Atmospheric Mercury Assessment: Sources, Emissions and Transport* report (UNEP Chemicals Branch, 2008), current Hg emissions to the global atmosphere come from three types of source: new emissions from **natural** (i.e., geogenic) sources, new emissions from **anthropogenic** sources, and **re-emission** of historically-deposited Hg which originally came from both anthropogenic and natural sources.

Natural sources – mercury released from the Earth's crust by the continuous and ubiquitous natural weathering of Hg-containing rocks or by geothermal activity, or Hg emitted during episodic events such as volcanic eruptions. Over the past hundreds to thousands of years, Hg emissions from natural weathering globally can be assumed to have been fairly constant, with variations largely associated with changes in volcanic and geothermal activity (see Figure 2.16 later in this chapter). Current annual (geogenic) releases to air from natural sources are estimated at around 80–600 t/y (Mason et al., 2012, see Figure 1.2) and 300 t/y (Corbitt et al., 2011).

Anthropogenic sources – mercury released as a result of current¹ human activities. Anthropogenic sources result in Hg emissions to the atmosphere (discussed in this chapter) and Hg releases to aquatic systems (considered in Chapter 4). Estimates of current anthropogenic emissions to the atmosphere are around 2000² t/y. Section 2.2 presents a

detailed inventory of current anthropogenic emissions to air totalling 1960 (1010–4070) t/y in 2010.

Some anthropogenic sources release Hg as a result of man's use of mineral resources as fuels and as raw materials in industrial processes, including metal production, in particular processes that involve heating materials to high temperatures. These sources involve human activities that (intentionally or unintentionally) release Hg from crustal rocks and/or expose rocks and ore bodies that would otherwise remain buried to surface weathering processes. Mercury is present as an impurity in fossil fuels (coal in particular), ores mined for ferrous and non-ferrous metal production and other minerals used in the production of materials such as cement. Although the Hg is generally present in low concentrations, the considerable volumes of these materials that are extracted and used and the high temperature processes involved can result in substantial Hg releases to the atmosphere. Mercury is itself produced commercially by mining and extraction of Hg ore (cinnabar), however, compared with other primary anthropogenic sources, Hg production is a minor component. Because the environmental releases of Hg associated with these activities are an artefact of the processes involved, the associated emissions are sometimes termed 'by-product' or 'unintentional' emissions. Many industrial sites such as old mines and decommissioned chlor-alkali plants exhibit high levels of local Hg contamination, and Hg emissions from these contaminated sites can continue for long periods after operations have ceased.

A second category of anthropogenic sources are those that release Hg to the atmosphere following its intentional use. These intentional uses include Hg use in artisanal and small-scale gold mining (ASGM) and certain industrial and chemical processes, and in man-made products that contain Hg. These products include certain types of energy saving and fluorescent lamps, batteries, electrical devices and instruments (including Hg thermometers), paints, cosmetics, and some pesticides and fungicides. Releases occur during manufacturing, and following breakage and/or disposal of Hg-containing products. Associated anthropogenic sources include releases from (controlled and uncontrolled) incineration of waste, and from wastes in (contained) landfills or (uncontained) dumps, or contaminated sites. Recycling of materials, including secondary ferrous metal production, results in some Hg emission, as does Hg use in dental amalgams where cremation of human bodies results in release of Hg from dental fillings to the atmosphere. One of the human uses of Hg with the highest associated Hg emissions is its use for extracting gold in ASGM. Mercury emissions to the atmosphere also occur from its use in the chlor-alkali industry in Hg-cell caustic soda production. Use of Hg in the production

¹ Current in this discussion refers to the current year; current emissions are therefore those that take place within the current annual period, as opposed to historical or past emissions that took place at some point in time before the current annual period.

² Global inventories, in particular past global inventories of anthropogenic emissions to air do not necessarily include all relevant sectors and activities. There will therefore be additional anthropogenic emissions from sectors not quantified. The most recent inventories, including that presented in this report are assumed to cover the most important anthropogenic emission sectors/activities; sectors that are not addressed include those identified in Section 2.2.4.2.

of vinyl chloride monomer (VCM) is a potentially significant source for which emissions are still not quantified.

Re-emissions – these comprise Hg releases to the atmosphere that are derived from past natural and anthropogenic releases. Under the right conditions, Hg can be (re-)emitted to the atmosphere from the Earth's surfaces (soil, rocks, snow and ice, surface waters – including ocean surface water, and vegetation) that have previously received Hg either from atmospheric deposition or through another transport pathway. Re-emission sources tend to be diffuse and are associated with 'environmental reservoirs' of Hg that have accumulated over time, particularly in organic surface soils and surface ocean waters.

Estimates of current annual re-emissions to the atmosphere that are a legacy of historical Hg releases from both anthropogenic and natural sources are in the range 4000–6300 t/y (Mason et al., 2012; see Section 1.2).

An important fact to remember concerning re-emission sources is that the origin of the re-emitted Hg is both natural and anthropogenic. Re-emitted Hg has been deposited at some point in the past and the original release sources can no longer be distinguished. Releases of Hg associated with anthropogenic activities have increased dramatically since humans started to use Hg over 1000 years ago, but especially with the onset of significant burning of fossil fuels that started with the (European) industrial-revolution in the 19th century, and the widespread use of Hg in gold and silver mining in other regions. This has loaded the environmental reservoirs – thus enhancing re-emission sources. A major reason, therefore, for controlling current anthropogenic Hg emissions is to reduce this 'input' so that environmental reservoirs of Hg can be gradually depleted by natural processes that 'permanently' remove Hg from the system (such as burial in deep sea sediments). Controlling anthropogenic Hg emissions therefore reduces present-day emissions and also acts to reduce (future) re-emission from environmental reservoirs of Hg. Controlling current anthropogenic emissions is thus the only option for limiting the amount of 'new' Hg entering the global biogeochemical cycle.

For the reasons discussed above, it is important that re-emission sources, despite the fact that they are associated with natural Hg environmental cycling processes, are not considered to be a component of 'natural' emissions, which is how they have been treated in some studies. Although the (original) sources of the Hg that enters the air through re-emissions cannot be identified as natural or anthropogenic, it is also important to recognise that human activities can enhance re-emissions. Examples of ways human activities can enhance re-emissions include: intentional biomass burning (as opposed to natural wildfires); coal bed fires started accidentally during human activities (as opposed to natural fires); and potentially as a result of (human induced) climate change (e.g., increased wildfires, thawing of permafrost and increased microbial activity that impacts Hg cycling).

It is not yet clear how climate change will affect the balance between Hg atmospheric deposition and re-emissions. This

may vary regionally as, for example, sea-ice cover decreases in some areas and precipitation increases or decreases in others; however, independent of other factors, it is expected that rising temperatures would be likely to increase the re-emission of (semi-)volatile substances such as Hg from the Earth's surfaces to the atmosphere. On this basis, it also follows therefore that decision-makers can instigate actions that can decrease re-emissions – by reducing the anthropogenic sources that add Hg to environmental reservoirs but also through other actions that may mitigate conditions that promote re-emissions.

One consequence of the large reservoirs of Hg already in the environment is that there is likely to be a time-lag of at least decades, depending on the reservoir, before emissions reductions have a demonstrable effect on Hg levels in human food-chains (other than in situations involving high local contamination). This is particularly so for Hg levels in marine food chains. It is imperative, therefore, that international efforts to reduce current emissions begin as soon as possible, because delays in action now will inevitably lead to future delays in noticeable reductions of Hg in the world's ecosystems.

2.1.2 Global mercury budgets and estimates of emission from natural and re-emission sources

As described in Section 1.2, total annual Hg emissions to the atmosphere have been variously estimated at between 5500 and 8900 t/y. Current Hg emissions to the atmosphere from natural sources are estimated at ca. 80–600 t/y (Mason et al., 2012). Mercury is emitted from volcanoes primarily as gaseous elemental mercury (GEM). Estimates of Hg emissions from volcanoes are generally based on the Hg/SO₂ (mercury / sulphur dioxide) ratio, with ratios of 1.18×10^{-5} , 1.16×10^{-5} and 5.88×10^{-6} suggested for erupting volcanoes, continuously degassing volcanoes and ash rich plumes, respectively (Ferrara et al., 2000a; Nriagu and Becker, 2003; Mather and Pyle, 2004). Mercury emissions from calderas may also represent an important natural source of Hg (Ferrara et al., 1998). Lack of relevant data and order of magnitude variation in some of the factors involved mean that these estimates are highly uncertain (Pyle and Mather, 2003; Mather and Pyle, 2004).

Re-emissions from soils and vegetation and from oceans are estimated at ca. 1700–2800 t/y and 2000–2950 t/y respectively (Mason et al., 2012), corresponding to about 60% of total annual emissions to the atmosphere. Re-emissions from land and vegetation are about twice those from oceans on a unit area basis. Due to its volatility, GEM is an important component in the cycling of Hg between soil and air and several studies have shown that Hg volatilisation increases with increasing soil moisture content (Schlüter, 1993; Steinnes, 1997; Kabata-Pendias and Mukherjee, 2007). Mercury in soils can be converted to methylated forms and transported to aquatic ecosystems, contributing to total methylmercury loading and bioaccumulation.

Mercury accumulates in vegetation mainly through uptake from the atmosphere and atmospheric deposition to foliage (Rea et al., 2002). The atmospheric contribution to the total Hg content of the leafy parts of plants is of the order of 90–95% and 30–60% for roots (Mosbaek et al., 1988; Eriksen et al., 2003; Eriksen and Gustin, 2004). Mercury uptake from soils appears to be insignificant (Lindqvist et al., 1991; Schuster, 1991; Grigal, 2003; Karpinska, 2005). Biomass burning (from wildfires and agricultural burning) has been estimated to contribute 675 ± 240 t/y of Hg to the atmosphere (Friedli et al., 2009), with a strong seasonality depending on the emission region concerned. This value is close to the estimate used in global budget models. Much of this therefore constitutes a re-emission of previously deposited atmospheric Hg.

Re-emissions from oceans constitute more than 96% of re-emissions from the Earth's surface waters (Mason et al., 2012); the remainder is from lakes and other surface waters. There is a significant latitudinal gradient of GEM evasion from tropical to polar oceans, with annual means ranging from ~ 33 ng/m²/d near the equator to ~ 3 ng/m²/d at 60° N (Strode et al., 2007). This pattern is believed to reflect regional changes in average biological productivity and sunlight irradiance. Mid-latitude evasion displays a large seasonal cycle induced by biological productivity. Ocean evasion rates are also elevated downwind of industrial regions (e.g., Pirrone

et al., 2003). Rates of evasion can be very high in shallow waters such as the Mediterranean Sea, where rates vary from about 60–190 ng/m²/d in different sectors from open waters to coastal polluted sites (Gårdfeldt et al., 2003; Andersson et al., 2007). In lakes with high dissolved organic carbon and Hg content, evasion rates can reach up to 130 ng/m²/d (Boudala et al., 2000).

Figure 2.1 illustrates the major components of the global Hg budget that introduce and remove Hg from the atmosphere (see also Figure 1.2). An important consideration to note is that reduction in the current anthropogenic Hg flux to the atmosphere (2) will ultimately reduce the related fluxes (3–5) that determine environmental Hg levels at the Earth's surface.

The United Nations Environment Programme (UNEP) has requested that this report be developed as a contribution to international efforts to reduce anthropogenic Hg emissions. Within this context, therefore, the remainder of this report focuses on (quantification of) anthropogenic Hg emissions to air rather than natural emissions. The essential points from the above discussion are that approximately 30% of current annual Hg emissions to air are due to anthropogenic sources. But as well as this, current anthropogenic emissions are continuing to load up the environmental pools of Hg that give rise to the re-emissions that account for a further 55–60% of current annual emissions to air.

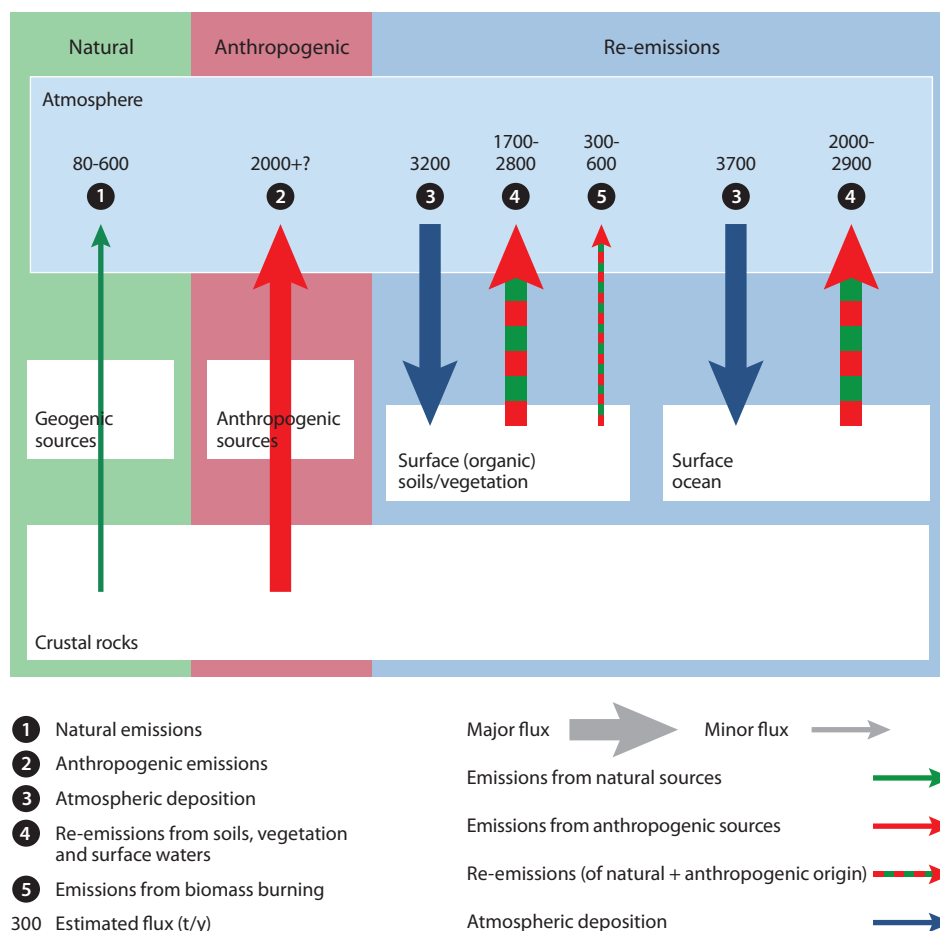


Figure 2.1. Schematic illustration of the main sources of mercury to the atmosphere showing natural, anthropogenic and re-emission components, and fluxes between the atmosphere and various surface environmental compartments. Flux estimates are in t/y as derived from Mason et al. (2012) (see also Figure 1.2).

2.2 Estimating global anthropogenic mercury emissions to air for 2008–2010: Methodology

A key component of this work to update the 2008 *Global Atmospheric Mercury Assessment: Sources, Emissions and Transport* report (UNEP Chemicals Branch, 2008; AMAP/UNEP, 2008) is the production of a new global inventory³ of anthropogenic Hg emissions to the atmosphere. This new inventory has the target year of 2010 – however recognising that information required to produce such inventories may not yet be available for all countries, the basis for most of this new inventory is latest available data from the period 2008–2010.

2.2.1 Methods for estimating emissions

Various methods are employed to estimate emissions of Hg at the plant/facility, national, regional and global level. In general, they fall under one of two main categories:

- *Mass-balance/substance-flow based estimates:* These work on the principle of what goes in must come out. Amounts of Hg in fuels and raw materials constitute the inputs; and the outputs are the amounts of Hg emitted to air, discharged to water/land, retained in products or in wastes, or otherwise recovered and stored or disposed of. Inputs and outputs are assumed to balance and the calculation methods employed are relatively straight forward. Accuracy and precision of the estimates typically depend on the availability of the information that defines the inputs and the validity of assumptions regarding the pathways involved (i.e., whether releases are to air, water, waste-streams, etc.). Estimates made using mass-balance approaches have been characterised as low accuracy for low-level emissions, but moderate accuracy for long-term averages, moderate precision, and low-cost (Mazzi et al., 2006). Costs are higher when these include costs of analysis of fuels, raw-materials and wastes, etc.
- *Measurement-based estimates:* These rely on measurements made at appropriate points in the industrial process or in the product/waste output streams to define the emissions to air or releases to water, land, waste products, etc. The high costs associated with some monitoring/analysis systems mean that they are only deployed for continuous monitoring at some facilities. Many measurements-based emissions estimates therefore rely on a relatively few measurements. Accuracy and precision of the resulting estimates therefore often depends on the validity of extrapolating ‘snap-shot’ measurements made at infrequent intervals to longer periods, or measurements made at ‘representative’ plants to other facilities with similar operations. Emission estimates that apply to an entire year (or even shorter periods) will

depend on how representative the measurements made at a particular instant in time are for the overall operations at the plant – which will change as different fuels and raw materials are introduced, and different operating conditions are applied. Estimates based on measurements have been characterised as having greater accuracy for low-level emissions, but lower accuracy for long-term averages, and higher precision, but high associated costs, especially for continuous monitoring systems.

Since the 2005 inventory (AMAP/UNEP, 2008; Pacyna et al., 2009) was produced, the number of direct measurements of emissions from certain point sources (in particular power plants and some metal and cement production and waste incineration facilities) has increased considerably, resulting in a much improved information base.

In a number of countries (including the USA, Canada, Australia, and EU Member States) legal and/or regulatory systems have been introduced that require regular reporting of emissions. Increasing use is being made in these reporting systems of measurement-based estimates and facility-level reporting, in particular for major point sources. A number of these systems support pollution release inventories (PRI) and/or emissions inventories (E-PRTR, 2012; LRTAP, 2012; Environment Canada, 2012; Australian Government, 2012; US EPA, 2012). Some of these systems include an ‘emissions threshold’ above which plants are required to report their emissions (typically 5 kg/y as for the Canadian NPRI, or 10 kg/y for the European Pollutant Release and Transfer Register, E-PRTR). Different national rules and procedures apply when it comes to checking and auditing the reported facility emissions.

In other countries, national Hg emissions have only recently been quantified for the first time. Since 2005 and the start of the UNEP negotiating process in 2010, many countries have initiated work on national emission inventories which, in several cases, have yielded much improved information on activity data, sector characteristics and Hg emissions. A number of such inventories make use of the ‘UNEP Toolkit’ for identification and quantification of Hg releases (UNEP 2011a,b) (see Section 2.2.3).

It is important to recognise that all emission estimates, whether national, global, or for an individual plant, and whether based on mass-balance approaches or measurements, are *estimates*. These estimates rely on the validity of various underlying assumptions. Improving the accuracy of estimates (i.e., reducing their inherent uncertainty) depends on improvements in the quality of the information available to support and better constrain the assumptions.

For the purposes of developing a global inventory of emissions to air, it was beyond the scope of the work to consider emissions at the detailed facility-level, and even incorporation of national estimates is problematic – for reasons discussed in Section 2.3.2. Consequently, for the 2010 inventory, a mass-balance approach was employed with the aim of deriving a complete global inventory using a common approach for all countries (see discussions in Section 2.2.3).

³ ‘Inventory’ in this context means a compilation of the estimated emissions to air from various sectors and sources; there are known source sectors for which it is not (yet) possible to quantify emissions, and possibly also sectors that have not yet been recognized as significant sources of Hg emissions to air.

2.2.2 Previous inventories

The 2008 report (AMAP/UNEP, 2008) included an inventory of anthropogenic Hg emissions to the atmosphere for 2005, which reflected the state-of-the-art at that time. The new (2010) inventory produced for this report, however, represents a radical departure in how data are compiled and used to produce (global) emissions inventories, and includes a comprehensive overhaul of the methodology applied. It is therefore relevant to describe these developments.

Global inventories of Hg emissions to the atmosphere have been produced at approximately five-year intervals since 1990 (Pacyna and Pacyna, 2002; Pacyna et al., 2006, 2009; AMAP/UNEP, 2008). All of these inventories have used the same basic approach for the major (by-product) emission sectors. Namely, for a set of defined emission sectors, national emissions estimates are calculated by multiplying data on the associated ‘**activity**’ (i.e., statistics on consumption of fuels or raw materials used, or amounts of products such as cement or metals produced) by an ‘**emission factor**’ – a value representing the amount of Hg released to the atmosphere per amount of material consumed/produced (Figure 2.2). The emissions factors applied have been **abated emission factors**, that is, emission factors that incorporate the effects of Hg emission controls due to abatement technology, yielding the abated emissions estimates⁴.

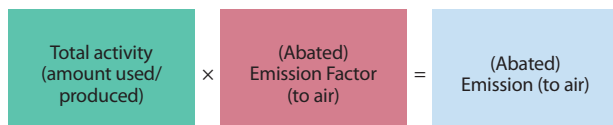


Figure 2.2. Method used to calculate emissions estimates in previous global inventories.

In the 2005 global inventory prepared in connection with the UNEP 2008 report (AMAP/UNEP, 2008) and the AMAP 2011 Mercury Assessment (AMAP, 2011), an additional component was introduced. This concerned estimating emissions from certain ‘intentional-use’ sectors not considered in previous global inventories, using a mass-balance approach based on regional Hg consumption patterns. The amounts of Hg entering into waste-streams from disposal of Hg-containing products were modelled, and emission factors applied to calculate associated emissions to air. In addition, estimates were introduced for a major emissions sector associated with use of Hg in ASGM that had not been included in previous global inventories.

Making comparisons between the global inventories prepared since 1990 is problematic for the following reasons:

1. Inventories prepared for different years used different statistical sources for activity data, generally with improvements in completeness of the information in later years; in some cases different procedures and assumptions were made when assigning activity data.

2. Inventories prepared for different years include different combinations of sectors, with additional (intentional use) sectors being added to the 2005 inventory in particular.
3. For many sectors, inventories prepared for different years tended to use the same (abated) emission factors; however, in some cases emission factors were adjusted between the different inventories as better information became available.

As a consequence of this, and in connection with the AMAP assessment (AMAP, 2011) and UNEP Paragraph-29 Study (UNEP, 2010a) the inventories prepared since 1990 were re-calculated in an attempt to gain insight into the effects of the above factors on the implied changes in global anthropogenic Hg emissions over time (AMAP, 2010) (see Section 2.4).

In relation to point (3), the use of the same (abated) emission factors for inventories representing emissions over the period 1990–2005 is, in itself inappropriate. This is because it poorly reflects the reality of the situation where, in particular the technologies applied in processing fuels and raw materials (including technologies to reduce emissions) may have changed significantly over the past 20 years. In cases where adjustments were made, these generally concerned new assumptions regarding the Hg content of fuels and raw materials rather than addressing changes in technology. This issue was not addressed in the re-analysis of past global Hg inventories by AMAP (2010).

2.2.3 New inventory, new methodology

As noted above, one major limitation of the methods employed to produce previous global inventories of anthropogenic Hg emissions to air (including the 2005 inventory) was that these inventories were based on the application of a single (abated) emission factor⁵ per sector. That is to say, for any given sector, the same (abated) emission factor (and therefore underlying assumptions) was employed for calculating emissions from all countries, irrespective of the obvious fact that in reality countries differ substantially, both in respect of the fuels and raw materials used and the technologies employed.

This problem is addressed to some degree in the approach adopted in the **UNEP Toolkit** for identification and quantification of Hg releases. The UNEP Toolkit is a series of guidelines and spread-sheet tools developed by UNEP that allow countries to identify and quantify their Hg releases (UNEP, 2011a,b). The Toolkit offers default factors for the calculation of inputs (termed ‘**input factors**’, which are somewhat comparable to (unabated) emission factors); it also invites countries to introduce an additional factor (an ‘**output scenario**’) to take into account a basic selection of Hg emission control technologies.

The UNEP Toolkit input factors calculate total Hg releases for the sectors concerned, and emissions to air are determined by the application of an air ‘**distribution factor**’ (i.e., the proportion of

⁴ Abated emissions estimates refer to emissions after the application of control technologies to reduce emissions; unabated emissions refer to emissions prior to the application of these control technologies.

⁵ An emission factor reflecting emissions after the application of emission abatement technologies.

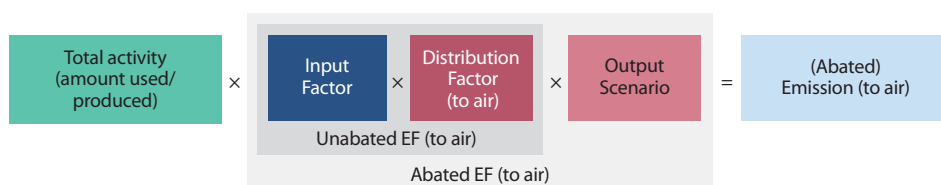


Figure 2.3. Method used to calculate emissions estimates in the UNEP Toolkit approach.

the total release that is assumed to be released to air, as opposed to land or water, etc.). In combination, the UNEP Toolkit **input factor** and **distribution factors** are equivalent to an **unabated emission factor** for the media/pathway concerned (Figure 2.3). Because the UNEP Toolkit is a basic release inventory development tool, it is often used in the 'default mode', with the default input factors and output scenarios being applied. The result is that many of the release estimates produced have a very large associated range (values produced using the minimum and maximum default factors). Most UNEP Toolkit applications employ only a single input factor and output scenario factor, thus the input factor still needs to reflect the proportion of Hg released from the entire mix of fuels and/or raw materials that are used within a given sector in the country, and the output factor the 'aggregated' effect of, for example, any technologies applied to control emissions.

The Toolkit approach does offer the possibility for all countries to use assumptions and specific emission factors that are applicable for their own situation – as opposed to a single uniform set of factors – as applied to previous global inventory estimates. However, producing a global emission inventory using the Toolkit would require that all countries develop and use their own Toolkit application, and all for the same year (or restricted period). To date, the Toolkit has been applied by approximately thirty countries, and for years ranging from 2004 to 2009.

Taking the above into account, it was decided that a new approach was needed for the work to prepare the 2010 global inventory of anthropogenic Hg emissions. The work involved four main components:

1. The development and application of new systems for estimating emissions from main (by-product and some intentional-use) sectors based on a mass-balance approach.

This included the development of two database modules, the first to compile and document **activity data**, the second to maintain data on **(unabated) emission factors** and emission reduction technology employed in different countries and to calculate unabated and abated emissions.

In addition to improved possibilities to take into account differences in fuels and raw materials and the technologies employed in different countries, the new methodology also includes a more detailed breakdown of emissions between different sectors/activities than that employed in previous inventories. An important refinement in this connection is the partitioning of emissions (and the assumptions and factors that are used to calculate them) associated with combustion of fossil fuels in power plants, industrial uses, and other (e.g. domestic/residential burning) (see Section 2.2.4).

The conceptual approach employed to produce this component of the 2010 inventory is illustrated in Figure 2.4, and can be compared with Figures 2.2 and 2.3 that describe the approaches used in preparing the 1990–2005 global inventories, and the UNEP Toolkit approach.

2. The refinement and application of the (substance-flow) model previously employed (AMAP/UNEP, 2008) to quantify emissions from wastes associated with Hg-containing products (i.e., certain intentional-use sectors), based on regional Hg consumption data.
3. The refinement and application of the model previously employed (AMAP/UNEP, 2008) to quantify emissions from dental amalgam as a result of human cremation.
4. The updating of information on emissions associated with ASGM. Because of the nature of this activity (largely

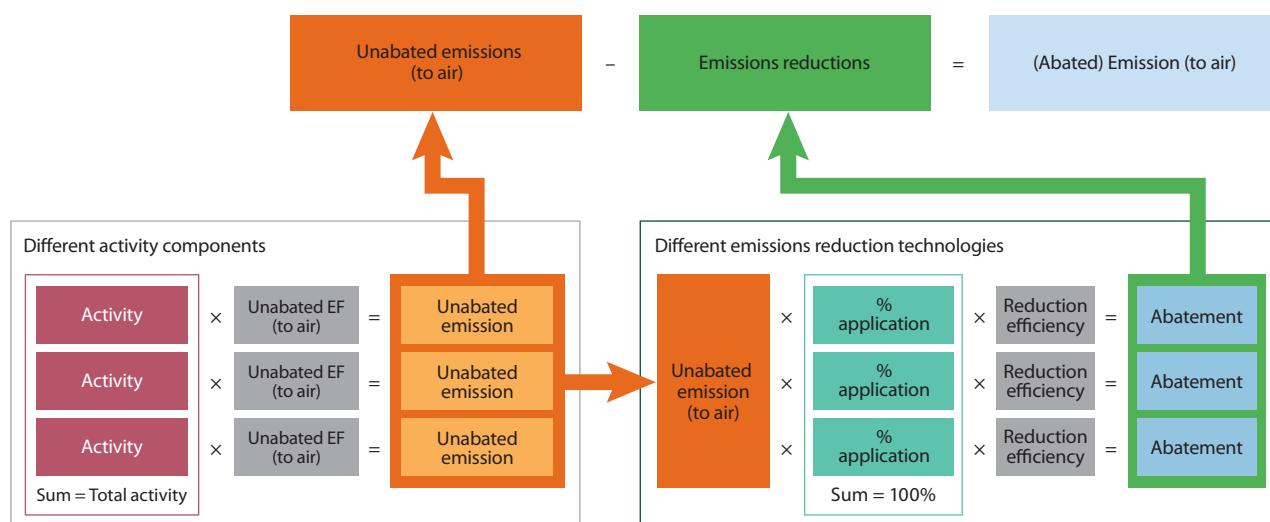


Figure 2.4. Method used to calculate emissions estimates (to air) for the 2010 inventory estimates.

unregulated and illegal in some countries) official data and statistics regarding the extent of ASGM activities are generally lacking or incomplete. For this reason, emissions estimates were prepared by the Artisanal Gold Council, utilising information that is compiled in and accessible through the Mercury Watch website (www.mercurywatch.org). This was the only component of the 2010 inventory that, for some countries, utilised information from earlier than 2008.

A key aspect in developing global emission inventories is transparency in terms of the assumptions made, and the underlying emission factors and activity data utilised in preparing the various inventories. The documentation included in the 2008 technical report (AMAP/UNEP, 2008) was intended to provide more of this information in an accessible form for the 2005 global inventory. However, in view of the ongoing UNEP process to negotiate a global Hg agreement, and the attention this is focusing on Hg emissions, it is increasingly important to be transparent and make accessible comprehensive documentation regarding all the data, assumptions, and calculation methods that constitute the basis for any given emission estimate. The UNEP Toolkit provides transparency in documenting the data that are used to calculate emission estimates; however the decision process behind a country employing a particular input factor or output scenario factor is not always entirely clear. Transparency and documentation of the data and assumptions underlying any given estimates are also critical if future estimates and inventories are to be reliably compared with the 2010 inventory estimates.

For this reason, this chapter includes an extensive set of annexes, with comprehensive discussions of the methods employed to produce estimates for each of the four components described above. These annexes include worked examples and background data relating to activity statistics and emissions factors and technology assumptions used, etc. The relevant Annexes are numbered as follows:

- Annex 1: Method used to estimate 2010 mercury emissions to air from main 'by-product' emission sectors and the chlor-alkali industry, including an example calculation.
- Annex 2: Method used to estimate 2010 mercury emissions to air from artisanal and small-scale gold mining, including an example calculation.
- Annex 3: Method used to estimate 2010 mercury emissions to air from wastes associated with intentional use sectors, including an example calculation.
- Annex 4: Method used to estimate 2010 mercury emissions to air from use in dental amalgam and human cremation.
- Annex 5: Activity data used in the calculation of emission estimates.
- Annex 6: Emission factors and technology profiles used in the calculation of emission estimates.

2.2.3.1 Regionalisation

As previously mentioned, one of the objectives of the new inventory methodology was to overcome the limitation of applying 'universal' (abated) emission factors – that is, the same factors to all countries. In order to better reflect differences in the situations of different countries concerning their technological characteristics and procedures for handling waste, countries were grouped together with other countries believed to have similar technological and/or waste management characteristics. The initial groupings applied were those suggested by Streets et al. (2011), and these groupings were subsequently modified based on expert opinion and information made available to the project group. The resulting country groupings formed the basis for assigning generic technology or waste management profiles that were used in the emissions estimation methodology. In this way, the (already limited) information available for some countries regarding emission factors and technological factors could be used to fill the many gaps in information for other countries in their respective groups. The groupings of countries employed in the estimation of emissions for the main industrial sectors and intentional-use sectors respectively are illustrated in Figures 2.5 and 2.6. The use of these profiles is described in the methodological descriptions in Annexes 1 and 3.

2.2.4 Sectors and activities

2.2.4.1 Sectors and activities quantified in the 2010 inventory

The inventory estimates in the new 2010 global inventory of anthropogenic Hg emissions to air cover the following main emission 'sectors':

- Stationary combustion of fossil fuels (coal, oil and natural gas) in power plants.
- Stationary combustion of fossil fuels (coal, oil and natural gas) in industrial/commercial uses.
- Stationary combustion of fossil fuels (coal, oil and natural gas) for domestic/residential heating, and uses of coal, (crude, diesel and fuel) oil and gas in transportation, agriculture and fishing.
- Cement manufacture (including co-incineration of waste).
- Production of ferrous metals (primary pig iron production).
- Production of non-ferrous metals (primary production of copper, lead and zinc).
- Production of aluminium⁶.
- Production of mercury metal.
- Mercury emissions from oil refining (other than emissions associated with on-site combustion for power/heat)⁶.
- Production of gold from large-scale mining.
- Production of gold from artisanal and small-scale gold mining.

⁶ Mercury emissions from production of aluminium and from oil refining have not been included in previous global inventories.

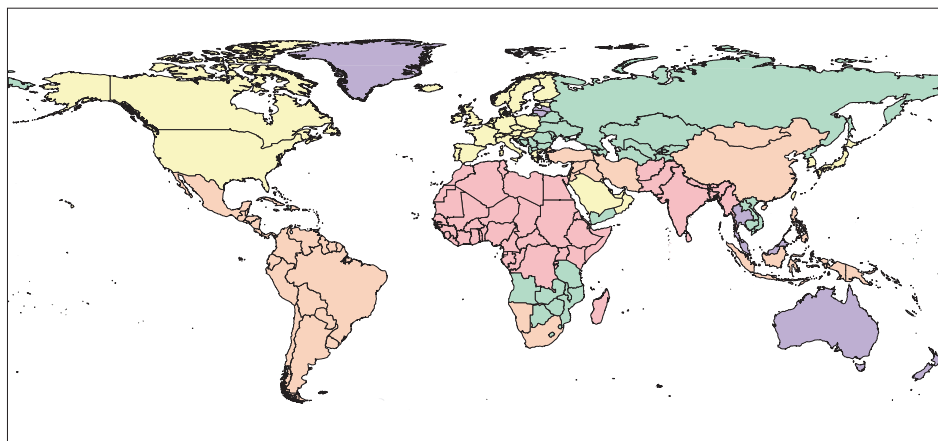


Figure 2.5 Regional groupings applied in the definition of technology profiles associated with mercury emissions from energy and industrial sources.

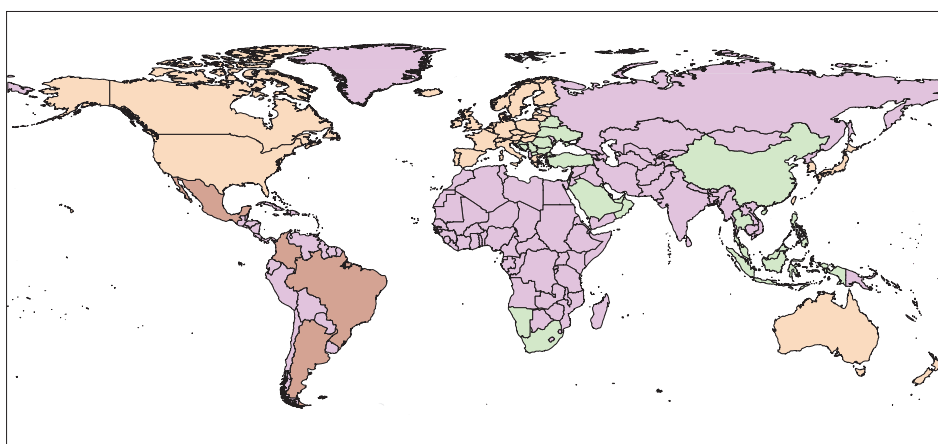


Figure 2.6. Regional groupings applied in the definition of waste management profiles associated with mercury emissions from intentional-use sectors.

- Mercury emissions from chlor-alkali industry (Hg-cell technology).
- Mercury emissions from product waste incineration and other product waste disposal.
- Mercury emissions from its use in dental amalgams resulting from human cremations.

The first ten items are associated with by-product or unintentional Hg releases; the latter four are associated with intentional-uses of Hg (and related waste streams). These emission sectors are essentially the same as those addressed in the 2005 global emissions inventory, with the addition of emissions from aluminium production and oil refineries.

Another new addition to the 2010 inventory is the inclusion of an estimate of emissions from contaminated sites (sites with elevated Hg content relative to local background, as a consequence of Hg use or its presence in a variety of products and industrial processes, such as old mine tailings and industrial sites – including some closed chlor-alkali plants – that are generally no longer operating but that are contaminated as a result of past human activities). Emissions estimates from this source are based on information reported in Kocman et al. (2013).

A further new feature of the 2010 inventory is that several of these sectors, in particular the stationary combustion sectors, have been sub-divided into additional component ‘activities’ – so-called because they each have associated ‘activity’ data relating to statistics on levels of consumption or production.

Thus, for example, in previous inventories, for countries lacking more detailed national inventories, activity data relating to coal and oil consumption were used to estimate emissions – applying a very coarse assumption that 50% was used in power plants and 50% in domestic residential heating. The new methodology compiles activity data not only for power plant, industrial and domestic/residential/transportation fuel burning separately, it also distinguishes between different types of coal and oil consumed. These improvements allow for better characterisation of the fuels in terms of the (unabated) emission factors associated with them. Thus, rather than using a single emission factor for coal burning it is now possible to assign different factors for different types of coal used within a particular country for a particular purpose. The disadvantage of this is, of course, that a more detailed information base needs to be compiled on activity statistics; however such data are increasingly available from national sources, and from international statistical databases such as those compiled by the International Energy Agency (IEA) and the US Geological Survey (USGS) (see Section 2.2.5).

Table 2.1 presents an overview of the relationship between sectors, activities, and also the abbreviations that are used to refer to these various components in the inventory outputs. It also includes information on the relationship between these sectors/activities and the sectors employed for reporting under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP).

Table 2.1. Classification scheme for sectors and their sub-activities employed in the 2010 inventory.

Sector (code)	Component activities (code)	Release category	Relevant LRTAP NFR sector coding(s) ^a
Stationary fossil fuel combustion (SC) in (major) power plants (SC-PP) Coal combustion (SC-PP-coal)	Combustion of hard coal (anthracite) (HC-A-PP) Combustion of hard coal (bituminous coals) (HC-B-PP) Combustion of brown coal (sub-bituminous coals)(BC-S-PP) Combustion of brown coal (lignite)(BC-L-PP)	By-product	1A1a Public electricity and heat production [Sum of emissions from all fuels. Can include waste incinerated for energy recovery.]
Stationary fossil fuel combustion (SC) in (major) power plants (SC-PP) Oil combustion (SC-PP-oil)	Combustion of crude oil (CO-PP) Combustion of heavy fuel oil (CO-HF-PP) Combustion of light fuel oil (CO-LF-PP)	By-product	
Stationary fossil fuel combustion (SC) in (major) power plants (SC-PP) Natural gas combustion (SC-PP-gas)	Combustion of natural gas (NG-PP)	By-product	
Stationary fossil fuel combustion (SC) in industrial uses (SC-IND) Coal combustion (SC-IND-coal)	Combustion of hard coal (HC-IND) Combustion of brown coal/lignite (BC-IND)	By-product	Stationary combustion in manufacturing industries and construction: 1A2a Iron and steel 1A2b Non-ferrous metals 1A2c Chemicals 1A2d Pulp, Paper and Print 1A2e Food processing, beverages and tobacco 1A2f Other [Sum of emissions from all fuels]
Stationary fossil fuel combustion (SC) in industrial uses (SC-IND) Oil combustion (SC-IND-oil)	Combustion of crude oil (CO-IND) Combustion of heavy fuel oil (CO-HF-IND) Combustion of light fuel oil (CO-LF-IND)	By-product	
Stationary fossil fuel combustion (SC) in industrial uses (SC-IND) Natural gas combustion (SC-IND-gas)	Combustion of natural gas (NG-IND)	By-product	
Stationary fossil fuel combustion (SC) in other uses (domestic/residential uses, transport, and use in fisheries, agriculture) (SC-DR) Coal combustion (SC-DR-coal)	Combustion of hard coal (HC-DR) Combustion of brown coal/lignite (BC-DR)	By-product	1A4ai Commercial / institutional: Stationary; 1A4bi Residential: Stationary plants; 1A4ci Agriculture/Forestry/Fishing: Stationary [Sum of emissions from all fuels]
Stationary fossil fuel combustion (SC) in other uses (domestic/residential uses, transport, and use in fisheries, agriculture) (SC-DR) Oil combustion (SC-DR-oil)	Combustion of crude oil (CO-DR) Combustion of heavy fuel oil (CO-HF-DR) Combustion of light fuel oil (CO-LF-DR)	By-product	
Stationary fossil fuel combustion (SC) in other uses (domestic/residential uses, transport, and use in fisheries, agriculture) (SC-DR) Natural gas combustion (SC-DR-gas)	Combustion of natural gas (NG-DR)	By-product	
Production of iron and steel (PISP)	Primary production of pig iron (PIP)	By-product	2C1 Iron and steel production 1B1b Solid fuel transformation 1B1c Other fugitive emissions from solid fuels 1A2a Iron and steel, stationary combustion [2C1 Includes also secondary steel. 1B1b/c includes coke production Emissions may be classified as process emissions (2C1) and/or emissions from stationary combustion (1A2a) and/or include coke production (1B1b/c).]
Non-ferrous metal production (aluminium, copper, lead and zinc production) (NFMP, NFMP-AL, NFMP-CU, NFMP-PB, NFMP-ZN)	Production of aluminium from bauxite – primary production (AL-P)	By-product	2C3 Aluminium production 1A2b Non-ferrous metals [Includes also secondary aluminium. Emissions may be classified as process emissions (2C3) and/or emissions from stationary combustion (1A2b).]
	Production of refined copper – primary production (CU-P) Production of refined copper – total production (CU-T) (used for some countries where CU-P is not separately quantified)	By-product	2C5a Copper production 2C5e Other metal production 1A2b Non-ferrous metals, stationary combustion [Includes also secondary copper. May be reported included in a sum for all non-ferrous metals in 2C5e. Emissions may be classified as process emissions (2C5a/e) and/or emissions from stationary combustion (1A2b).]

	Production of refined lead – primary production (PB-P) Production of refined lead – total production (PB-T) (used for some countries where PB-P is not separately quantified)	By-product	2C5b Lead production 2C5e Other metal production 1A2b Non-ferrous metals, stationary combustion [Includes also secondary lead. May be reported included in a sum for all non-ferrous metals in 2C5e. Emissions may be classified as process emissions (2C5b/e) and/or emissions from stationary combustion (1A2b).]
	Production of refined zinc – primary production (ZN-P) Production of refined zinc – total production (ZN-T) (used for some countries where ZN-P is not separately quantified)	By-product	2C5d Zinc production 2C5e Other metal production 1A2b Non-ferrous metals, stationary combustion [Includes also secondary zinc. May be reported included in a sum for all non-ferrous metals in 2C5e. Emissions may be classified as process emissions (2C5d/e) and/or emissions from stationary combustion (1A2b).]
Non-ferrous metal production (mercury) (NFMP-HG)	Production of Hg (primary sources) (HG-P)	By-product	2C5e Other metal production 1A2b Non-ferrous metals [May be included in a sum for all non-ferrous metals in 2C5e. Emissions may be classified as process emissions (2C5e) and/or emissions from stationary combustion (1A2b).]
Non-ferrous metal production: Large-scale gold production (NFMP-AU)	Production of gold from large-scale mining (GP-L)	By-product	2C5e Other metal production 1A2b Non-ferrous metals, stationary combustion [May be included in a sum for all non-ferrous metals in 2C5e. Emissions may be classified as process emissions (2C5e) and/or emissions from stationary combustion (1A2b).]
Artisanal and small-scale gold production (ASGM)	Production of gold (artisanal /small-scale) (GP-A)	Intentional use	2C5e Other metal production [May include emissions from all/other nonferrous metals production.]
Cement production (CEM)	Production of Portland cement (CEM)	By-product	2 A 1 Cement production 1 A 2 f i Other stationary combustion [Emissions may be classified as process emissions (2 A 1) and/or emissions from stationary combustion (1 A 2 f i).]
Caustic soda production (CSP)	Chlor-alkali industry using Hg-cell process, based on plant Cl ₂ production capacity (CSP-C) or Cl ₂ production amount (CSP-P)	Intentional use	2B5a Other chemical industry [Includes all other chemical industries except ammonia production, nitric acid production, adipic acid production and carbide production.]
Oil refining (OR)	Refining of crude oil in oil refineries (CO-OR)	By-product	1A1b Petroleum refining 1B2ai Exploration, production, transport 1B2aiv Refining / storage 1B2c Venting and flaring [May include venting/flaring of natural gas]
Dental use (DENT)	Use in dental amalgam, emissions from human cremation (CREM)	Intentional use	6Cd Cremation
Waste (WAS)	Incineration of waste (large incinerators) (WI)	Intentional use	6Cc Municipal waste incineration [6Cc may include uncontrolled waste incineration. Waste incinerated for energy recovery may be included in 1A1a Waste incineration, irrespective of origin may be reported as a sum under one of the 6C categories]
	Waste and other losses due to breakage and disposal in landfill, etc. (WASOTH) [Industrial waste incineration and incineration of sewage sludge are not included in the 2010 emissions estimates.]	Intentional use	3D3 Other product use 6Ca Clinical waste incineration (6Cb Industrial waste incineration) 6Ce Small scale waste burning 6D Other waste
Contaminated Sites (CSITE)	Contaminated sites associated with no longer operational mining activities and closed industrial plants (CSITE)	Past use	?

^a Reporting of emissions under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) is done using a specified format (NFR-reporting templates) (www.ceip.at/reporting-instructions/annexes-to-the-reporting-guidelines). When comparing emissions from sectors, in the reporting tables Parties have the possibility to make their own choices to aggregate emissions from several sources and report a notation key IE (included elsewhere) if this is clearly explained in the accompanying Inventory report.

2.2.4.2 Sectors and activities not quantified in the 2010 inventory

In addition to identifying the sectors that are included in the 2010 global inventory calculations, it is important also to identify the (potentially relevant) sectors and activities that are not (yet) addressed or fully quantified in the inventory. These include:

- Secondary metal production⁷
- Production of manganese and/or manganese alloys (e.g., ferro- manganese alloys)
- VCM production with Hg-dichloride catalyst
- Other manufacturing processes (pulp and paper manufacture, brewing and distilling, etc.)
- Emissions associated with incineration of sewage sludge
- Emissions associated with industrial waste (including incineration of industrial waste)
- Extraction of petroleum hydrocarbons (i.e., Hg emissions prior to refining/combustion of oil, from gas flaring, and prior to transport and combustion of gas)
- Releases from dental use during production and preparation of Hg amalgam fillings, and disposal of removed fillings
- Emissions associated with biofuel production and burning in power plants and industrial sectors
- Other anthropogenic biomass burning.

Emissions associated with some of these additional activities are quantified in national inventory compilations, and where these are compared with or introduced into the global inventory they are separately identified (see Annex 7).

2.2.5 Sources of data and information used in the 2010 inventory

Primary sources of data and information used in the production of the 2010 global emissions inventory are described in Table 2.2. In addition, comprehensive national data were provided, especially for Brazil, Japan, Republic of Korea, Mexico, and the USA, much of this through the members of the UNEP/AMAP contact group established to support the work to produce an updated 2010 global inventory of anthropogenic Hg emissions to air.

A large number of additional information and data sources were used as the basis for the work to determine (unabated) emission factors and ‘technology profiles’, in particular for country-specific emission factors and technology characterisations. These, together with comprehensive descriptions of the procedures employed are detailed in Annex 6.

⁷ Mercury emissions from secondary production of ferrous and non-ferrous metals are not included in the 2010 global inventory estimates as they were assumed to be minor in comparison to emissions associated with primary production. However, this may not be the case in some countries and this issue is discussed further in Section 2.3.3.3. Emissions associated with secondary steel production (which have been quantified in previous inventories) are now included in the re-cycling component of the estimates associated with wastes from intentional use sectors.

2.2.6 Relationship with the UNEP Toolkit

The databases compiled to support the current inventory work made use of the UNEP Toolkit (UNEP, 2011b) as a basis for development of in particular (unabated) emission factors (see Annex 6). In the course of this work, many of the Toolkit factors were adapted for the activity data concerned, or adjusted on the basis of additional information available from, for example, the Paragraph-29 study work (UNEP, 2010a), or from national and industry sources. As a result of this work, a parallel activity has been initiated by UNEP to update the UNEP Toolkit documentation.

Some points to note when comparing the UNEP Toolkit with the database approach adopted in this work:

- The databases are constructed to prepare global emission estimates, that is, estimates for all countries; whereas the Toolkit is designed for use on a country by country basis. The database is applied to all countries, for a single target year whereas the Toolkit applications (to date) are for a range of different years.
- The Toolkit produces estimates of releases to air, water and land, whereas the databases are (currently) only set up to estimate emissions to air.
- The activity statistics employed in the UNEP Toolkit are not always (readily) available at a global level. For example, the Toolkit calculates emissions from cement production on the basis of clinker production, which simplifies some of the underlying assumptions regarding the processes and sources of Hg involved. However, available (global) production statistics are for cement production, and not for clinker production. Consequently, the database represents a compromise between an ideal approach and one that is applicable for all countries.

Considering the results of Toolkit applications to date, agreement between Toolkit estimates and those produced in this work is variable. In part this reflects the differences in activity data (as many Toolkit applications are for years earlier than 2010). Also, the emission factors employed in the current work, although often based on the published Toolkit factors, have been revised for a number of sectors.

In general, and particularly once ongoing work to update the Toolkit has been completed, the databases developed to prepare global estimates can be expected to produce comparable – but not necessarily identical – results for emissions to air to those produced using the UNEP Toolkit. The databases may be expected to produce improved estimates for some countries where available national information can extend the options available in the Toolkit.

2.2.6.1 Potential future uses of the inventory databases

Optionally, the databases produced to prepare the 2010 global inventory could be employed in a ‘Toolkit mode’ – introducing the Toolkit default (or modified) emission factors and activity

Table 2.2. Primary sources of activity and other related data used.

Sector	Activity data ^a	Unabated emission factors ^b	Technology ^b	Other
Coal burning in power plants, industrial and domestic / residential / transport applications	IEA-SB ^c	UNEP, 2010a,b, 2011b,c,d; BREF, 2006	UNEP, 2010a,b, 2011b,c,d; BREF, 2006	
Oil burning in power plants, industrial and domestic / residential / transport applications	IEA-SB ^c	UNEP, 2011b; BREF, 2006	UNEP, 2011b; BREF, 2006	
Natural gas burning in power plants, industrial and domestic / residential / transport applications	IEA-SB ^c	UNEP, 2011b	UNEP, 2011b	
Cement production	USGS, 2009/2010	UNEP, 2010a, 2011b; BREF, 2010	UNEP, 2010a, 2011b; BREF, 2010	CSI, 2005 (waste co-incineration); CEMBUREAU, 2010
Ferrous metal (pig iron) production	Worldsteel Association, 2011	UNEP, 2011b; BREF, 2012a	UNEP, 2011b; BREF, 2012a	
Non-ferrous metal (Cu, Pb, Zn) production	USGS, 2009/2010	UNEP, 2010a, 2011b; BREF, 2009	UNEP, 2010a, 2011b; BREF, 2009	
Aluminium production	USGS, 2009/2010	UNEP, 2011b		
Mercury production	USGS, 2009/2010	UNEP, 2011b		
Large-scale gold production	USGS, 2009/2010	UNEP, 2011b		
Artisanal and small-scale gold production	Artisanal Gold Council	Artisanal Gold Council/ UNEP Partnership on Reducing Mercury in Artisanal and Small-scale Gold Mining	Artisanal Gold Council/ UNEP Partnership on Reducing Mercury in Artisanal and Small-scale Gold Mining	
Chlor-alkali industry	UNEP/World Chlorine Council	UNEP, 2011b		OSPAR, 2011
Oil refining	IEA-SB	UNEP, 2011b; BREF, 2012b	BREF, 2012b	Wilhelm et al., 2007; IKIMP, 2012; IPIECA, 2012; Petroleum Association of Japan
Intentional-use sector emissions (and associated releases from waste incineration / disposal)	P. Maxson, pers. comm.			
Cremation (emissions from dental amalgam)	CSGB, various dates	UNEP, 2011b		
Contaminated sites				Kocman et al., 2013

^a See Annex 5; ^b See Annex 6; ^c IEA categories – SC-PP: Electricity plants, CHP plants, Heat plants, Energy industry own use; SC-IND: Industry; SC-DR: Transport, Residential, Commercial and Public Services, Agriculture/Forestry, Fishing, Other non-specified.

data – and potentially used to maintain Toolkit results over a longer period of time. The databases could also be readily extended to cover releases to land and water.

The database results can also be used to give insight into possible necessary adjustments that may be needed to the Toolkit default factors, to keep these up to date.

Bearing in mind the difficulties in comparing inventories produced at different times, it may be feasible at some point to use the compiled databases to simulate the approach used to produce past global inventories – out of academic interest. In this connection, however, the new methodology is considered to represent a significant improvement over approaches used in

the past. The databases compiled could be considered a starting point for a more organised structured approach to compiling and documenting the data and methods behind the calculations of global emissions inventories – and thus a strategy designed to make these more comparable in the future.

Finally, the databases compiled to support the current inventory work also make it possible to better attempt to establish emissions scenarios – for example by changing assumptions relating to (unabated) emission factors (e.g., resulting from changes in fuel sources and/or raw materials) or changing the technology profiles for various countries/sectors in a meaningful manner.

2.2.7 Uncertainties

Estimating the uncertainties associated with emission estimates; in particular estimates covered by the scope of a global inventory is a particular challenge. It was beyond the scope of the current project work to investigate this aspect in detail; therefore a relatively crude (and intentionally conservative) approach was adopted to provide some quantification of the scale of uncertainties in the estimates presented.

Uncertainties associated with the emission estimates presented in this report are considered to have three major components:

- uncertainties associated with activity data
- uncertainties associated with (unabated) emission factors
- uncertainties associated with assumptions made regarding applied (Hg emissions control) technologies.

In general, the uncertainties associated with emission factors (including plant operating conditions and technologies used to reduce Hg emissions) are assumed to be considerably more important in determining uncertainties in the overall emissions estimates than those associated with activity data. For example, the EMEP/EEA (2009) air pollutant emission inventory guidebook assigns uncertainties associated with activity data (not specific to Hg) of the order of ± 5 –10%. Evaluation of uncertainties associated with (emission factor-

based) estimates depends on the procedures involved. For estimates based on a small number of measurements at representative facilities (or engineering judgment based on relevant facts) or engineering calculations based on assumptions alone – which between them cover the case for most Hg emissions estimates – the uncertainties are considered to be of the order of $\pm 50\%$ to \pm an order of magnitude.

In order to provide some quantification of the uncertainties associated with the 2010 global inventory, upper and lower range emissions estimates for major emission sectors were calculated by applying the emissions calculation methodology (as described above) but using adjustments to key information components as described in Table 2.3.

For emissions based on Hg consumption in intentional-use sectors, and associated waste handling, upper and lower range estimates were produced using the respective upper and lower ranges of the Hg consumption data. These however do not reflect the considerable uncertainties associated with the assumptions made regarding Hg flow in waste streams and associated emission factors. Consequently uncertainties in estimates associated with these sectors were assigned at \pm a factor of 3.

Uncertainties associated with the assumptions regarding assignment of countries to particular 'country groupings' for applied technology or waste handling procedures were not taken into account.

Table 2.3. Procedures adopted for calculating low/high range emissions estimates.

Category	Lower range estimate	Upper range estimate	Source
Activity data derived from IEA / official national sources – OECD countries	Activity – 5%	Activity + 5%	Modified after EMEP/EEA, 2009
Activity data derived from IEA / official national sources – non-OECD countries	Activity – 10%	Activity + 10%	Modified after EMEP/EEA, 2009
Activity data derived from other sources	Activity – 30%	Activity + 30%	Based on AMAP/UNEP, 2008
Unabated emission factors (UEFs)	If lower UEF available, mid-range UEF ^a – 0.5 × the difference between the lower and mid-range UEF. Otherwise, 0.7 × UEF ^a for coal sectors; 0.01 × UEF ^a for large scale gold production; 0.5 × UEF ^a for all other sectors	If upper UEF available, mid-range UEF ^a + 0.5 × the difference between the mid- and upper-range UEF. Otherwise, 1.3 × UEF ^a for coal sectors; 1.99 × UEF ^a for large-scale gold production; 1.5 × UEF ^a for all other sectors	UEFs tabulated in Annex 6
Technology profile	Uncertainties associated with the applied assumptions regarding abatement technology were not introduced directly into the calculations. In connection with these assumptions, the assumptions concerning types of controls and degree of implementation are considered to be more critical than those concerning Hg emission reduction effectiveness. To partly account for this, uncertainties associated with UEFs were somewhat increased.		
Emissions estimates for intentional-use waste stream emissions and emissions from cremations	0.3 × Mid-range estimate	3 × Mid-range estimate	
Emissions estimates for ASGM	Mid-range estimate –30–75% depending on country	Mid-range estimate + 30–75% depending on country	

^a UEF as tabulated in Annex 6

For emissions associated with ASGM, low–high range estimates were derived based on assumed Hg use and evaluation of the quality of the available information base for the various countries.

The resulting upper and lower range emission estimates are reported together with the 2010 global inventory estimates presented in Annex 8.

The uncertainties implied by the upper and lower ranges assigned to the presented estimates are somewhat larger than those reported with some previous inventories. This may be counter-intuitive given the presumption of improvements in both the methodologies and information base on which the estimates are founded. However, it is a reflection of the conservative assumptions employed, and the fact that previous assessments of uncertainties may have been over-optimistic, in particular with regard to the major influence of relatively small adjustments to emission factors.

Very few countries quantify uncertainties in relation to their national emissions reporting. However, for comparative purposes, the uncertainties estimated by Finland in their report on (2009) Hg emissions to air prepared in connection with their reporting under the LRTAP Convention (SYKE, 2012) is included in Table 2.4.

2.2.7.1 Possible double counting issues

In the production of global inventories based on available activity statistics and emission factors derived from various sources, there is always a potential for double counting. For example, emission factors associated with industrial processes may or may not include fuels used in various parts of the process. By better distinguishing categories of fuel combustion, and by separately addressing unabated emissions and technologies associated with Hg control (abatement) technologies, efforts have been made to avoid potential double counting of emissions. More information on this aspect of the work can be found in Annex 6 where details of the emission factors and technology profiles used in the calculation of emission estimates are discussed.

2.2.7.2 Potential for underestimation

In addition to the uncertainties associated with specific estimates that have been made, the overall inventory total is also a reflection of the completeness of the sources for which estimates have been made. A number of sectors are identified above (Section 2.2.4) that are not included in the current inventory, and that may have significant associated emissions. Some of these sectors are further considered in the discussions below.

Table 2.4. Uncertainties assigned to Finnish (2009) national emissions reported to LRTAP.

EMEP/ NFR sector	Sector description	Uncertainty- lower, % ^a	Uncertainty- upper, % ^a
Energy Industries			
1A1a	Public Electricity and Heat Production	-35	33
1A1b	Petroleum refining	-80	80
Manufacturing Industries and Construction			
1A2a	Iron and Steel	-80	80
1A2b	Non-ferrous metals	-90	89
1A2c	Chemicals	-47	47
1A2d	Pulp, paper and print	-53	54
1A2e	Food-processing, beverages and tobacco	-73	72
1A2fi	Other	-45	45
Transport			
1A3bvi	Automobile tyre and break wear	-98	239
Other sectors			
1A4ai	Commercial institutional	-67	65
1A4bi	Residential plants	-84	85
1A4ci	Agriculture, forestry, fishing (stationary)	-55	56
1A5A	Other stationary (including military)	-68	66
Mineral Products			
2A1	Cement production	-50	50
2A2	Lime production	-100	101
Chemical Industry			
2B5a	Other	-52	51
Metal production			
2C1	Iron and steel production	-49	48
2C2	Ferroalloys production	-51	50
2C5d	Other	-100	98
Other			
2G	–	-100	100
3D3	–	-98	251
Waste Disposal			
6A	Waste disposal on land	-100	100
6Cb	Waste incineration	-42	43
6Cc	Waste incineration	-37	38
6Cd	Waste incineration	-95	249
Total		-22	22

^a Expressed as upper and lower bounds of 95% confidence interval relative to mean value.

2.3 Estimating global anthropogenic mercury emissions to air for 2008–2010: Results

Using the methods described above, the total estimated inventory of current (2010) anthropogenic Hg emissions to air is 1960 (1010–4070) t/y.

A complete listing of national emissions estimates obtained using the procedures described above, for various activity sectors, and including low and high range estimates is presented in Annex 8. These tabulations also include, where available comparative estimates from national sources. In light of an ongoing re-evaluation of default factors employed in the UNEP Toolkit, which is taking account of information acquired during the preparation of the 2010 inventory, estimates made using past applications of the UNEP Toolkit were not considered appropriate in most cases as most of these applications employed Toolkit default factors.

For some countries, comprehensive national emissions inventories for the period 2008–2010 are available (see Annex 7 and Section 2.3.2). Where such national inventories have an appropriate degree of documentation and transparency with regard to the basis for the estimates, these national estimates are suitable for use in the global inventory. In such cases they can be used to replace the estimates produced using the generic global inventory procedures – reflecting the fact that the information available to national authorities forming

the basis for the estimates (national activity data, emissions measurements at facilities, etc.) should be better than that available from (global) statistical compendia, literature reviews and associated assumptions, etc.

If national estimates for 2010 available from some countries (Canada, Japan, Korea, Mexico, the United States and European countries reporting under the LRTAP Convention) are introduced into the global inventory in place of the inventory estimates, the corresponding estimated total global anthropogenic emission to air is 1940 t, very similar to the estimate derived using the 2010 inventory methodology. As most national inventories do not include uncertainty ranges, it is not possible to assign a range to this number. The recognition of uncertainties is an important consideration and presenting single national estimates can convey a misleading picture of what is known and, more importantly, not known about emissions.

2.3.1 Inventory results by region and sector

On the basis of the inventory presented in Annex 8, Table 2.5 summarises the distribution of the estimates of global anthropogenic Hg emissions to air in 2010 according to sub-continental regions⁸.

Table 2.6 presents the results per region on a per capita basis, for ASGM and other sectors and their combination. Note here that the ASGM emissions are per capita for the entire regional population and not just for that part of the population engaged in ASGM activities.

Table 2.5. Global anthropogenic mercury emissions to air from different regions in 2010. IMPORTANT: These numbers cannot be compared directly with those presented in the 2008 assessment; see Section 2.4.

Sub-continent	2010 emissions (range), t ^a	%
Australia, New Zealand & Oceania	22.3 (5.4 – 52.7)	1.1
Central America and the Caribbean	47.2 (19.7 – 97.4)	2.4
CIS & other European countries	115 (42.6 – 289)	5.9
East and Southeast Asia	777 (395 – 1690)	39.7
European Union	87.5 (44.5 – 226)	4.5
Middle Eastern States	37.0 (16.1 – 106)	1.9
North Africa	13.6 (4.8 – 41.2)	0.7
North America	60.7 (34.3 – 139)	3.1
South America	245 (128 – 465)	12.5
South Asia	154 (78.2 – 358)	7.9
Sub-Saharan Africa	316 (168 – 514)	16.1
Region undefined ^b	82.5 (70.0 – 95.0)	4.2
Total	1960 (1010 – 4070)	100

^a Values rounded to three significant figures; ^b emissions from contaminated sites.

⁸ Note: for a definition of these sub-continental regions see Figure 2.8; the sub-continental regions employed in this breakdown have no relationship to the 'regionalisation' employed in the definition of technology and waste profiles (Section 2.2.3.1). Assignment of countries to the sub-continental regions identified in Table 2.5 can be found in Annex 8.

Table 2.6. Per capita anthropogenic mercury emissions to air in different regions in 2010.

Sub-continent	Per capita emissions, g	Per capita emissions from ASGM, g	Per capita emissions from other sectors, g
Australia, New Zealand & Oceania	0.79	0.00	0.79
Central America and the Caribbean	0.26	0.13	0.13
CIS & other European countries	0.34	0.04	0.30
East and Southeast Asia	0.37	0.13	0.24
European Union	0.19	0.00	0.19
Middle Eastern States	0.14	0.00	0.14
North Africa	0.08	0.00	0.08
North America	0.18	0.00	0.18
South America	0.65	0.49	0.16
South Asia	0.10	0.00	0.10
Sub-Saharan Africa	0.39	0.29	0.10
Global	0.28	0.11	0.17

Figure 2.7 and Table 2.7 summarise the distribution of the estimates of global anthropogenic Hg emissions to air in 2010 according to sector.

The majority of global anthropogenic emissions of Hg to the atmosphere in 2010 are associated with ASGM (37%) and stationary combustion of fossil fuels (24.7%, 24.2% from coal combustion). Other major emission sectors include non-ferrous metal production (15.5%, including copper, lead, zinc, aluminium, Hg, and large-scale gold production) and cement production (8.8%).

These results are generally consistent with the sector breakdown presented for the 2005 global inventory (UNEP Chemicals Branch, 2008) with one significant difference. In the 2005 inventory, emissions associated with fossil fuel combustion and ASGM were quantified at ca. 878 t and 350 t, respectively, corresponding to 45.6% and 18.2% of total emissions. In the 2010 inventory, in percentage terms, ASGM accounts for a higher proportion of emissions (37%) than coal combustion (ca. 25%). However, this should not be interpreted as a 'real' trend in terms of large increases in emissions from ASGM between 2005 and 2010, and large decreases in emissions from fossil fuel combustion over the same period. As described below (see Section 2.4.4), much of the apparent increase in ASGM associated emissions is attributed to improved information on ASGM activities in certain regions, and related new estimation methods. As far as the apparent change in emissions from coal burning is concerned, this has two contributing components:

1. In the power generation and industry sectors, new information on coal Hg content has resulted in a lowering of the emissions factors. In the 2005 inventory, abated emission factors of 0.1–0.3 g/t coal were employed. In the 2010 inventory, unabated emission factors combined with information and assumptions regarding efficiency of Hg emission controls at these point sources resulted in (global

average) effective abated emission factors (that is global emissions divided by global activity numbers for the sector concerned) of ca. 0.07 g/t for coal burned in power plants and 0.13 g/t for coal burned in industrial sectors. In terms of tonnes of emissions, if the 2010 methodology is applied to the 2005 coal consumption data (see Section 2.4.3) the resulting revised emission estimate for 2005 (ca. 460 t) is about 20% lower than that published in the AMAP/UNEP (2008) report for coal burning in power plants. This reflects the lower

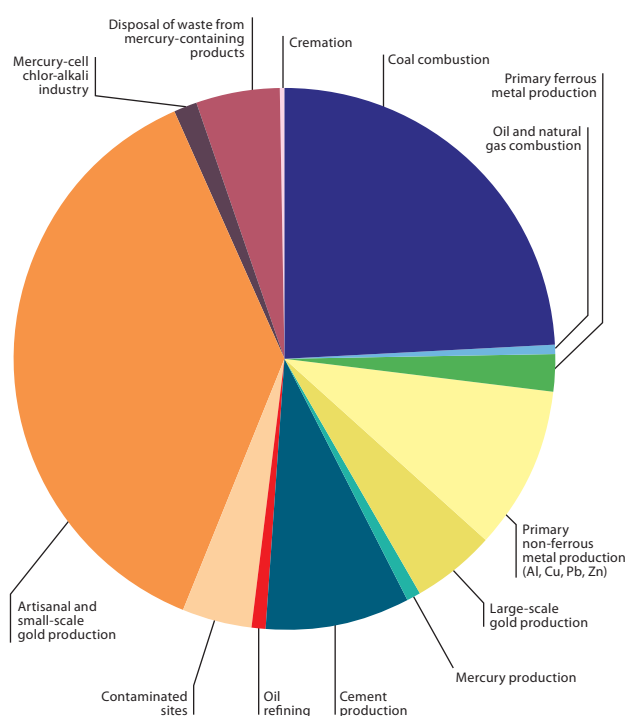


Figure 2.7. Proportions of global anthropogenic mercury emissions to air in 2010 from different sectors.

Table 2.7. Global anthropogenic mercury emissions to air from different sectors in 2010. IMPORTANT: These numbers cannot be compared directly with those presented in the 2008 assessment; see Section 2.4.

Sector	2010 emission (range), t ^a	%
Artisanal and small-scale gold mining	727 (410 – 1040)	37.1
Coal combustion – power plants	316 (204 – 452)	16.1
Coal combustion – industry	102 (64.7 – 146)	5.2
Coal combustion – other	56.0 (35.4 – 80.0)	2.9
Oil combustion – power plants	3.7 (1.7 – 6.1)	0.2
Oil combustion – industry	3.0 (1.4 – 5.0)	0.2
Oil combustion – other	2.6 (1.2 – 4.2)	0.1
Natural gas combustion – power plants	0.3 (0.1 – 0.5)	0.0
Natural gas combustion – industry	0.1 (0.0 – 0.2)	0.0
Natural gas combustion – other	0.2 (0.1 – 0.3)	0.0
Pig iron production (primary)	45.5 (20.5 – 241)	2.3
Non-ferrous metal production		
(Al, Cu, Pb, Zn)(primary)	194 (82.0 – 660)	9.9
Large-scale gold production	97.3 (0.7 – 247)	5.0
Mercury production	11.7 (6.9 – 17.8)	0.6
Cement production	173 (65.5 – 646)	8.8
Chlor-alkali industry (Hg cell)	28.4 (10.2 – 54.7)	1.4
Oil refining	16.0 (7.3 – 26.4)	0.8
Waste from consumer products (landfill)	89.4 (22.2 – 308)	4.6
Waste from consumer products (controlled incineration)	6.2 (1.5 – 21.9)	0.3
Cremation	3.6 (0.9 – 11.9)	0.2
Contaminated sites	82.5 (70.0 – 95.0)	4.2

^a Values rounded to three significant figures.

emission factors used. The fact that the revised 2005 estimate (410 t) is very similar to the 2010 estimate of ca. 420 t (for the comparable sectors) supports the conclusion that increasing global coal consumption in power and industrial sectors is being offset by improvements in power plant generating efficiency and wider introduction of Hg emissions control.

2. In the ‘other’ coal-use sector (much of which is associated with domestic and residential coal burning) the story is somewhat different. In 2005, an emission factor of 0.3 g/t was applied to this activity. In addition, since activity data on coal consumption broken down between various sub-sectors was not available for most countries, an assumption was made that ca. 50% was burned in the power/industry sectors and 50% in domestic/residential coal burning. In this case, Hg abatement is not a major consideration. Estimated emissions in 2010 (ca. 56 t) are considerably lower than those reported in the 2005

inventory (375 t) partly due to the use of a lower emission factor, but mainly due to the lower activity data obtained through reported consumption in this sector as opposed to an assumed 50% of total coal consumption. Using the 2010 methodology on 2005 activity and assuming that total coal consumption in 2005 is divided between power, industry and other uses in similar proportions to that in 2010, a revised 2005 emission estimate of ca. 50 t from this sector is obtained. On this basis it could be concluded that emissions from domestic and residential coal burning were over-estimated in the 2005 inventory.

The 2005–2010 comparisons are further discussed in Section 2.4.

Figure 2.8 presents the 2010 inventory results graphically by region and sector. In this illustration, the emissions associated with ASGM are shown separately (so that distributions can be compared more readily between regions with and without ASGM); ASGM symbols are scaled to match those representing emissions from other sectors. The illustration clearly depicts the relative contribution of East and Southeast Asia to global anthropogenic Hg emissions to air, and of some regions in the southern hemisphere to emissions from ASGM.

2.3.2 Comparison of estimates with national reported inventories

During the course of the work to prepare the 2010 inventory, several countries provided comprehensive national emission estimates for years between 2008 and 2010 (Canada, Denmark, Finland, France, Japan, Republic of Korea, Mexico, Norway, Sweden, USA). Other countries (Argentina, Brazil, South Africa) provided comparable information for certain sectors. Additional national estimates are also available from national pollution release inventories and other regional systems (such as reporting under the LRTAP Convention (LRTAP, 2012), and OSPAR Convention reporting of chlor-alkali industry emissions in the OSPAR area (OSPAR, 2011)).

In preparing the 2010 global inventory, an approach was used whereby emissions estimates were produced for all countries using a common methodology, with transparent access to the data and assumptions used to obtain the various estimates. This approach was intentionally designed to ensure a common basis for comparisons. As such, the resulting inventory and methods employed are not ‘tuned’ for producing the most accurate estimates for any given country or sector. At the same time, detailed national information is critical, both for constraining assumptions and establishing factors that could be applied to other countries with similar situations but lacking their own inventories.

An important test of the validity of the methodology therefore involved comparison of derived inventory estimates with reported national estimates, or estimates produced using other approaches. This was done in an iterative manner, so that where discrepancies were identified, discussions were held to try to understand the reasons for these. Where appropriate,

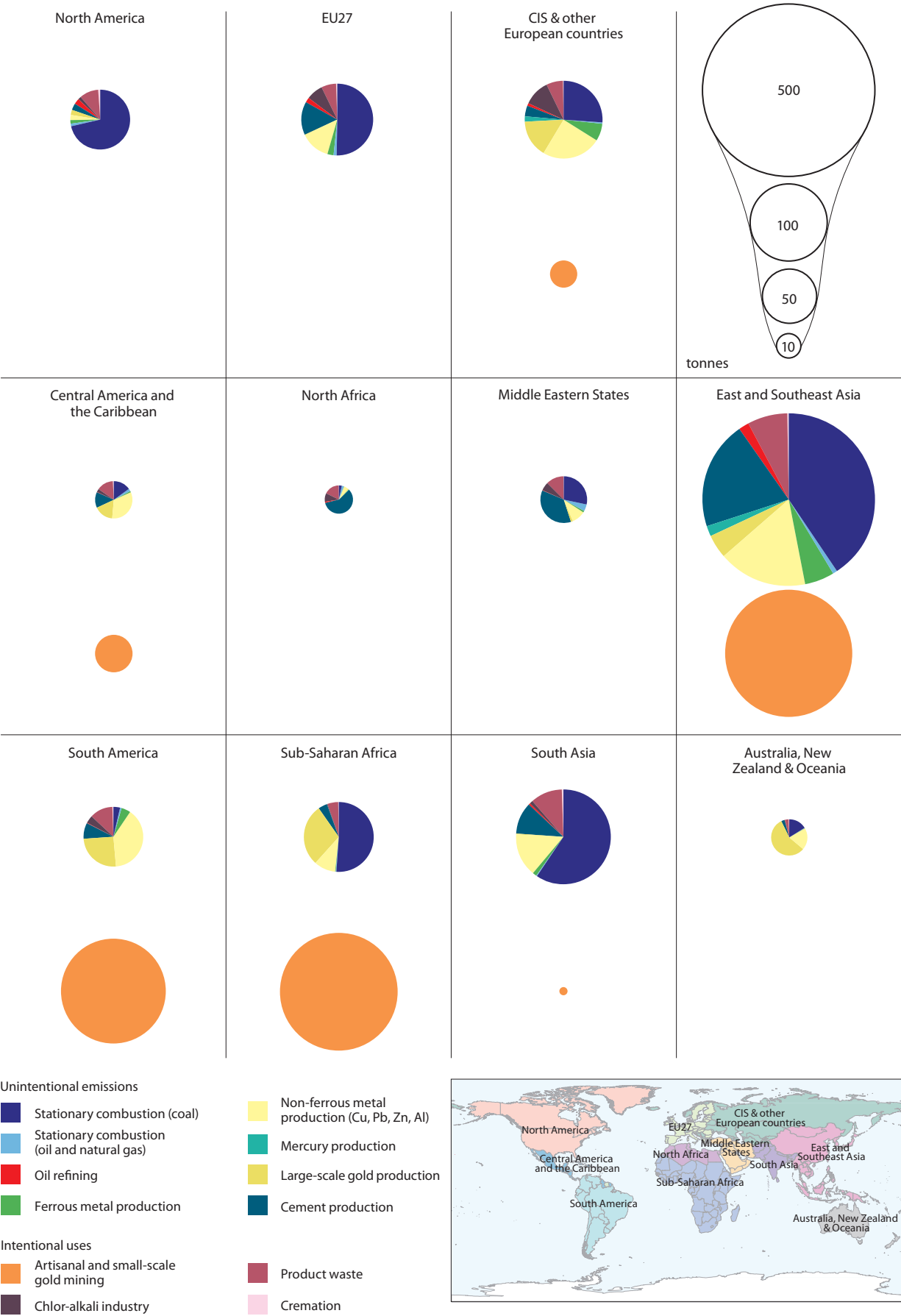


Figure 2.8. Regional pattern of global anthropogenic mercury emissions to air in 2010 from different sectors (does not include emissions from contaminated sites).

Table 2.8. Comparison of 2010 inventory derived estimates with nationally reported estimates for 2010 (USA for 2008).

Country	Estimate obtained from the 2010 global inventory, t	Reported total national emissions, t	Reported national emissions (national reporting) – comparable sectors ^a , t	Reported national emissions (national reporting) – other sectors, t	Reported national estimate from LRTAP reporting – comparable sectors ^a , t
Australia (and Christmas Island)	21.346	21.604	8.152	13.452	
Austria	0.889	0.986			0.984
Belgium	1.950	2.052			1.757
Bulgaria	8.146	0.884			0.866
Canada	4.470	5.450	4.023	1.427	
Cyprus	0.206	0.127			0.127
Czech Republic	4.896	3.480			3.458
Denmark	0.507	0.440			0.413
Estonia	0.874	0.632			0.632
Finland	1.515	0.898			0.828
France	4.926	4.177			3.225
Germany	17.730	9.292			9.020
Greece	6.513	6.513			
Hungary	1.455	0.781			0.689
Ireland	0.438	0.424			0.402
Italy	4.598	9.520			9.115
Japan	17.228	19.624	17.790	1.834	
Korea- Republic of	7.223	8.039	8.039		
Latvia	0.044	0.076			0.075
Lithuania	0.120	0.387			0.387
Malta	0.014	0.011			0.007
Mexico	23.392	20.519	20.142	0.377	
Netherlands	1.803	0.686			0.673
Norway	0.670	0.580			0.452
Poland	11.758	14.846			14.358
Portugal	0.981	2.055			2.038
Romania	5.027	5.337			5.292
Slovakia	0.950	1.184			0.860
Slovenia	0.497	0.661			0.652
Spain	5.980	7.818			7.454
Sweden	0.772	0.554			0.510
Switzerland	0.533	1.054			0.939
United Kingdom	4.820	6.291			4.642
United States	56.262	55.597	44.686	10.911	

^a 'comparable sectors' are intended to relate to sectors quantified in the 2010 global inventory. The LRTAP/NFR sectors included in this grouping are as follows: 1A1a, 1A1c, 1A2a, 1A2b, 1A2c, 1A2d, 1A2e, 1A2f, 1A2fii, 1A3biii, 1A3c, 1A3di(ii), 1A3dii, 1A4ai, 1A4bi, 1A4bii, 1A4ci, 1A4cii, 1A4ciii, 1A5a, 2C1, 2C3, 2C5a, 2C5b, 2C5d, 2C5e, 2A1, 1A1b, 1B2aiv, 6Cd, 6Cc, 6Ce, 3D3, 6D.

Note: Precise alignment of sectors used in different reporting systems is not straightforward and the categorisations in the table above are made employing a basic interpretation of sector descriptions.

Reported national estimate from LRTAP reporting – other sectors, t	Reported emissions from the European Pollutant Release and Transfer Register, t	Source
		Australian Government, 2012
0.002	0.092	LRTAP, 2012; E-PRTR, 2012
0.295	0.979	LRTAP, 2012; E-PRTR, 2012
0.018	0.000	LRTAP, 2012; E-PRTR, 2012
		Environment Canada, 2012
0	0.115	LRTAP, 2012; E-PRTR, 2012
0.023	2.968	LRTAP, 2012; E-PRTR, 2012
0.027	0.172	LRTAP, 2012; E-PRTR, 2012
0	0.593	LRTAP, 2012; E-PRTR, 2012
0.070	0.476	LRTAP, 2012; E-PRTR, 2012
0.952	2.338	LRTAP, 2012; E-PRTR, 2012
0.272	7.540	LRTAP, 2012; E-PRTR, 2012
	2.222	LRTAP, 2012; E-PRTR, 2012
0.092	0.186	LRTAP, 2012; E-PRTR, 2012
0.022	0.011	LRTAP, 2012; E-PRTR, 2012
0.406	1.184	LRTAP, 2012; E-PRTR, 2012
		Suzuki, 2012, pers. comm.
		Seo, 2012, pers. comm.
0	0.012	LRTAP, 2012; E-PRTR, 2012
0		LRTAP, 2012
0.004		LRTAP, 2012
		Solórzano, 2012, pers. comm.
0.013	0.491	LRTAP, 2012; E-PRTR, 2012
0.127	0.063	LRTAP, 2012; E-PRTR, 2012
0.488	3.019	LRTAP, 2012; E-PRTR, 2012
0.017	0.323	LRTAP, 2012; E-PRTR, 2012
0.045	1.192	LRTAP, 2012; E-PRTR, 2012
0.323	0.241	LRTAP, 2012; E-PRTR, 2012
0.009	0.045	LRTAP, 2012; E-PRTR, 2012
0.365	2.095	LRTAP, 2012; E-PRTR, 2012
0.044	0.135	LRTAP, 2012; E-PRTR, 2012
0.115	0.387	LRTAP, 2012; E-PRTR, 2012
1.649	3.582	LRTAP, 2012; E-PRTR, 2012
		US EPA, 2012

this dialog resulted in feedback that refined the methodology, resulting in improved convergence of respective estimates and also improvements in the information base used to derive estimates for other countries. This is considered an ongoing process that can and should be continued.

Table 2.8 presents a comparison of nationally reported emissions with the estimates derived using the 2010 inventory methodology for relevant countries. This table presents only a comparison of the total national estimates for the countries concerned. Annex 7 includes more detailed comparisons, including (where possible) comparisons of estimates for individual sectors.

In the table, an attempt is made to distinguish national emissions estimates that can be directly related to sectors quantified in the 2010 global inventory, from other sectors that may or may not be included. Precise alignment of sectors used in different reporting systems is not straightforward (for example, see comments relating to LRTAP reporting in Table 2.1). The categorisations in the table below are therefore made employing a basic interpretation of sector descriptions; it was beyond the scope of the work to conduct a more detailed analysis of this aspect.

A number of pollution release inventories based on facility-level reporting rely on operators and industry to report emissions, and most also have an associated threshold for reporting (e.g., site Hg emissions > 5kg per year for the Canadian PRI, or >10 kg per year in the case of the EU's E-PRTR). An analysis of the point sources listed in the comprehensive US EPA national emission inventory for 2008 indicates that ca. 15% of the reported emissions are from plants emitting <10 kg/y and more than 8% from plants emitting <5 kg/y. Emissions reported under the E-PRTR (see Table 2.8) constitute approximately 35% of total emissions reported by the same countries under the LRTAP reporting system. In this case, it is not possible to gauge whether there are many facilities in Europe with emissions <10 kg/y or whether emissions are under-reported. This illustrates the importance of the need to be aware of the basis for reporting under different systems, the need for checking and auditing of reported emissions, and above all transparency in reporting if estimates are to be credible.

There are therefore a number of reasons why estimates of Hg emissions produced in the 2010 inventory may not fully agree with national inventories made by countries using other methodologies. These reasons include:

- Reporting schemes may define and distinguish emissions source sectors in very different ways, and aligning these sectors may not be possible.
- Industry reporting to national government may be limited to sources with emissions above a certain threshold level so that emissions from smaller sources, below the threshold, are not reported. Where smaller sources make up a significant part of the source category, reported inventories may therefore significantly underestimate total Hg emissions.

- National inventories in some countries are making increasing use of actual measurements of Hg emissions at individual facilities. Measurement-based estimates are typically lower than estimates based on mass-balance approaches. At the global scale it is not yet feasible to base an inventory on individual site emissions.
- National reporting and monitoring schemes may have access to information that is not available to externally produced inventories.

Notwithstanding these comments, given the significant uncertainties associated with all emissions estimates, and the fact that they have often been made using different approaches, the level of agreement between the 2010 global inventory and nationally reported estimates is, with a few exceptions, surprisingly good. For some countries, where national information was used directly in the calculations of the global inventory estimates, consistent results might be expected, however for others, including most European countries, the 2010 inventory estimates are dependent entirely on use of default factors and generalised assumptions in the global inventory methodology. This level of agreement is an encouraging verification for the methodology employed to prepare the 2010 inventory estimates.

2.3.3 Discussion of results for selected sectors

The following information supplements and updates information presented in the 2008 assessment technical background report (AMAP/UNEP, 2008).

2.3.3.1 Stationary combustion of fossil fuels

Coal combustion remains a major source of anthropogenic Hg emissions, comprising 24.2% of the estimated emissions in 2010, with oil combustion contributing a further 0.5%.

The differentiation of the contributions from combustion in power plants, industry and domestic/residential burning permits improved evaluation of the currently applied emission controls and thus potential benefits of future abatement strategies.

Similarly, use of activity data for different types of coal (and oil) allows for better introduction of appropriate emissions factors in the emission estimation procedures. The current differentiation includes four basic coal types: the hard coals (anthracite and bituminous), and the brown coals (lignite and sub-bituminous), see Figure 2.9.

From an emission calculation perspective, one issue that came to light in the current work that has perhaps been neglected in previous work is associated with the moisture content of some brown coals. Coal Hg content is widely used as a basis for emission factors when estimating emissions from coal burning. Mercury content is generally reported on a dry weight basis, however even in recent reports this is not always clearly stated and some measurements refer to coal 'as received' (i.e., wet weight basis). Hard coals contain little moisture, however, some brown coals – for example some of the coals burned in Australia – may have moisture contents as high as 50%. The implication is that emission factors based on dry weight Hg content may not be appropriate for coals burned while still containing high moisture content. For example, a coal with 100 ppm Hg content on a dry weight basis, and a moisture content of 35% has an equivalent Hg content of 65 ppm on a wet weight basis – if these coals are not dried before they are burned, and the 100 ppm Hg content is used in an emission factor, this could result in a more than 50% overestimation of the emissions.

2.3.3.2 Cement production

A new factor affecting the estimates of Hg emissions is the increasing levels of co-incineration of waste and use of alternative fuels in cement kilns. (Unabated) emission factors

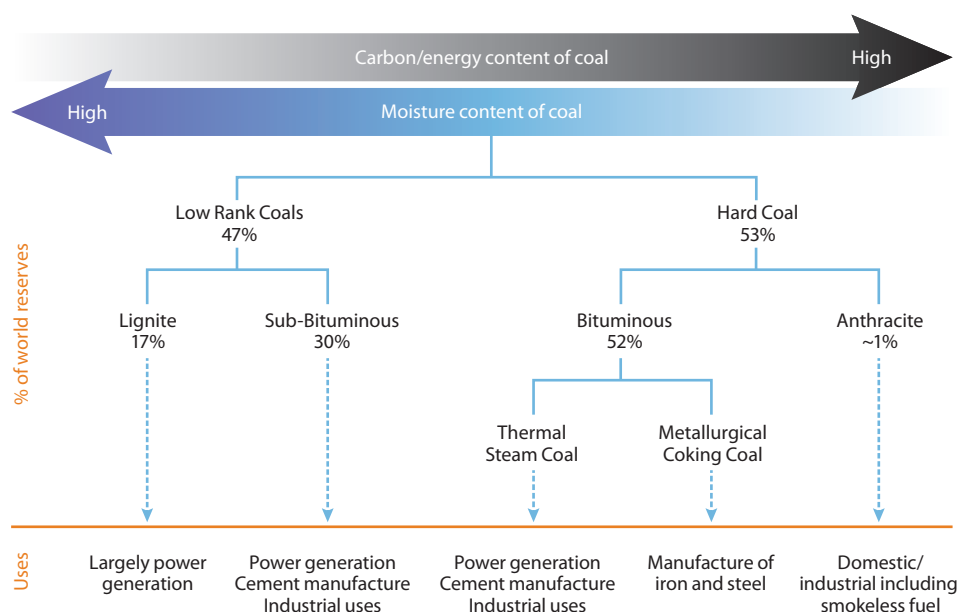


Figure 2.9. Coal types and their uses. Source: after World Coal Association.

associated with waste co-incineration are higher than those for use of coal, oil or petroleum coke alone as fuels in cement kilns (UNEP, 2011b), although regulations in some regions have been introduced to limit or prevent emission levels increasing as a result of this practice. In the United States National Emission Inventory (US EPA, 2012) some emissions from cement plants that are incinerating wastes are accounted under the hazardous waste incineration sector. To avoid double counting of coal and oil fuels, and to attempt to take account of fuel mixes and waste co-incineration in different countries, a number of nationally-relevant (unabated) emission factors were developed and applied in calculating emissions from cement production (see Annex 6). Bearing in mind that some of the emissions associated with fuels used in cement production are accounted elsewhere in the inventory, the emissions associated with cement production (ca. 8%) remain a major contribution in the global inventory. More information on use of alternative fuels and Hg emissions associated with waste co-incineration are required to reduce the uncertainties associated with emissions from cement production.

Recent trends in emissions associated with the cement sector are discussed in Section 2.4.7.

2.3.3.3 Iron and steel production

In the 2005 inventory, (abated) emissions factors were applied to steel production activity data. In the current inventory, estimates were produced based on production of (primary) pig iron including emissions from coke ovens, sinter plants, pellet plants, blast furnaces and basic oxygen steelmaking. Emissions associated with secondary steel production are only addressed in as far as the contribution from waste recycling that is accounted under the intentional-use sector emissions estimates.

The decision to focus on primary metal production was associated with the fact that electric arc furnaces do not have the Hg emission profile of blast furnaces, and an assumption was made that most scrap steel (raw material) would not be expected to contain much Hg. However, comparisons of the results obtained using this approach with estimates reported in national inventories indicates that, for most countries where such comparisons are possible, the national emissions estimates are higher. The national estimates generally do not distinguish between primary and secondary metal production and therefore also include emissions from secondary steel production.

Considering the United States and Canada, where national information provides some insight into respective emissions from primary and secondary steel production, it was surprising to note that the emissions from secondary production are apparently much higher than those from primary production. In the United States (2008) National Emission Inventory Hg emissions from primary and secondary steel production are 4530 and 577 kg, respectively; and in Canada 410 kg for primary + secondary compared with ca. 180 kg from primary production. If similar ratios were scaled to a global level this

would imply a considerable under-estimation (by a factor of between 2 and 7.8) in the global inventory of emissions from the ferrous metal sector. One possibility is that Hg-contaminated scrap metals are entering the process. The UNEP Toolkit bases its emission factor for secondary ferrous metal production on numbers of recycled vehicles, which are assumed to contain ca. 0.2–2 g of Hg per vehicle from Hg-switches and lamps. However, these devices have mostly been phased out some time ago or (in some countries at least) should be removed prior to re-cycling vehicles. This issue warrants further attention and indicates that the estimate for emissions associated with primary ferrous (and possibly non-ferrous) metal production in the global inventory may be on the low side due to lack of quantification of secondary metal emissions.

Recent trends in emissions associated with the (primary) ferrous metal sector are discussed in Section 2.4.8.

2.3.3.4 Non-ferrous metal production

The estimates presented in the current inventory for emissions from copper (Cu), lead (Pb) and zinc (Zn) production take better account of differences between artisanal and large-scale production methods (especially those with integrated acid plants) than previous inventories. A number of assumptions have been made regarding in particular the Hg capture by acid plants (assumed at 90%) and air pollution control devices (APCDs) downstream of the acid plants, and estimates could be improved by better information concerning specific application of technology in different countries. A number of complicating factors, including co-production of non-ferrous metals add further uncertainty to estimates for emissions from non-ferrous metal production.

The 2010 inventory includes estimates of emissions from aluminium (Al) production that have not been assessed in previous inventories. These estimates assume Al production from bauxite, rather than alumina (an intermediate product, a subject of free trade between the countries), due to the lack of availability of Hg inputs and outputs for alumina-based Al production. However, available activity data on primary Al production does not specify whether the metal was produced from bauxite or from (imported) alumina. Aluminium-producing countries with bauxite production include Australia, Brazil, China, Greece, India, Iran, Kazakhstan, Russia, United States and Venezuela. For other countries with Al production a lower emission factor was applied, reflecting an assumption that these countries base (more of) their production on alumina rather than bauxite.

The unabated emission factor for Hg production adopted from the UNEP Toolkit is only applicable to countries with dedicated Hg production (from cinnabar). Emissions estimates for Hg production were therefore made only for those countries with production from Hg mining (China, Kyrgyzstan, Morocco, Russia and Tajikistan). In other countries where Hg is a by-product of gold production (Chile and Peru) or zinc production (Finland) there may be some

associated emissions, but these are not separately quantified in the inventory. This may also be so for Mexico, where Hg is reclaimed from Spanish colonial silver mining waste.

Recent trends in emissions associated with the non-ferrous metal sector are discussed in section 2.4.8.

2.3.3.5 Large-scale gold production

Emission estimates from large-scale gold production (as distinct from production by ASGM) are considered preliminary and have large associated uncertainties. This reflects the fact that key information required for the calculation of emissions estimates – such as the gold content of ore, Hg content of ore, and amount of ore mined per tonne of gold produced – vary considerably both between and within countries – and over time. Representative information for individual countries is still largely lacking and therefore estimates are based on gross generic assumptions as described in Annex 6.

2.3.3.6 Chlor-alkali industry

Information on losses from the chlor-alkali industry in Europe is available from OSPAR (e.g., OSPAR, 2011) and from other countries through initiatives under UNEP and the World Chlorine Council (see UNEP, 2012). According to this information, there are around 100 chlor-alkali plants worldwide that still use Hg-cell technology, with associated Hg emissions to air. However, this number continues to decrease, as does the amount of Hg used per tonne of chlorine produced. Emissions of ca. 46 t of Hg from the chlor-alkali sector were reported in the 2005 inventory, compared with ca. 28 t in the 2010 inventory, and this trend is expected to continue as additional Hg-cell plants close or convert to other technologies. There are, however, still uncertainties relating to official information regarding emissions of Hg from the chlor-alkali industry and the fate of Hg unaccounted for in plant mass-balance calculations.

2.3.3.7 Oil refining

Emissions from oil refining have not been addressed in previous global inventories, and in the 2010 inventory are estimated to contribute a little under 1% of the total global inventory. This sector does not include emissions that may occur during extraction and transportation of crude oil and gas, or combustion of oil at refineries for power (which would be accounted under the industrial stationary combustion estimates). New information on Hg content of oils from different countries and regions was applied in developing revised emission factors that are being incorporated in revisions to the UNEP Toolkit.

2.3.3.8 Artisanal and small-scale gold mining

The estimate of Hg releases from artisanal and small scale gold mining (ASGM) is based primarily on field and industry reports from countries with active ASGM communities. The quality of the estimates ranges from good to reasonable to poor across the 72 countries known to have ASGM activities

(see Annex 2, Table A2.1). A first-order estimate of the amount and location of Hg being released into the global environment (atmosphere, land and water) by ASGM is readily obtained with an average estimated uncertainty of ca. $\pm 43\%$. Because the estimate is maintained continuously and updated whenever possible (www.mercurywatch.org), the current estimate (for 2011/2012) can be assumed to be equal to or greater than the releases for 2010 since no reduction in ASGM activity and associated Hg use has been noted over most of the past decade.

It is estimated that ASGM releases in 2011 averaged 1610 t Hg/y ($\pm 43.4\%$; range 910–2300 t/y) with 45.2% of this amount (727 t/y, range 410–1040 t/y) being emitted to the atmosphere. The remainder (880 t/y) was released to the hydrosphere (rivers, lakes, soils, tailings). However, a significant but unknown portion of the amount released into the hydrosphere is later emitted to the atmosphere when it volatilises (latent emissions). Results from historical gold rushes suggest that over a period of 100 years at least 70% of known inputs to the hydrosphere are subsequently released to the atmosphere. The 2010 estimate of emission to the atmosphere is significantly different to that reported for 2005 in the AMAP/UNEP (2008) assessment, both in terms of its magnitude and in the way the estimate has been made (see discussion in Section 2.4).

With a contribution of an estimated 727 t in 2010 to the global inventory of anthropogenic Hg emissions to air, ASGM sources are the largest contributing sector (37%); comparable to and slightly higher than fossil fuel combustion sources. ASGM emissions are dominated by sources in South America, Sub-Saharan Africa and East and Southeast Asia (see Figure 2.8).

2.3.3.9 Vinyl chloride monomer production

Although not included in the sectors quantified in the 2010 inventory, it is known that large quantities of Hg are used as a catalyst in the production of vinyl chloride monomer (VCM). A report developed by the China Council for International Cooperation on Environment and Development (CCICED, 2011) identified use of 800 t of Hg in this sector in China alone in 2012. Most VCM production is in China.

In 2009, a coal-based process was used at 94 of China's 104 VCM/PVC plants. From a use of between 540 and 970 t of Hg in the VCM/PVC industry in recent years, it was predicted that by 2012, China's VCM/PVC production would reach 10 million t with associated Hg consumption exceeding 1000 t. PVC production is planned to double between 2010 and 2020 (CCICED, 2011).

According to the CCICED (2011) report, little of the Hg used in VCM production is recycled; however, recent information from China indicates that the waste Hg catalyst is recycled and reused.

The ultimate fate of waste Hg catalysts from VCM production in China and elsewhere, and possible emissions to air and releases to water from Hg use in VCM are not yet adequately documented.

2.3.3.10 Dental amalgam

Emissions from use of Hg in dental amalgams resulting from cremation of human remains are estimated at 3.6 t (range 0.9–11.9 t) in 2010 globally (see Section 2.3.1). This estimate does not include Hg emissions associated with releases during production and preparation of Hg amalgam fillings and disposal of removed fillings. It is estimated that ca. 20–30% of total Hg consumption for dental uses (that is 70–100 t of the estimated 340 t of Hg currently used in dental uses) is likely to enter the solid waste stream. In addition, Hg in removed fillings goes to recycling, solid waste and wastewater (P. Maxson, pers. comm.).

A recent European Commission report (EC, 2012) estimated EU Hg demand for dentistry (in 2010) at around 75 t/y (range 55–95 t/y), of which about 45 t/y ends up in dental surgery effluents; only part of this is captured and treated as hazardous waste in compliance with EU legislation. According to this report, dental Hg waste constitutes some 21–32% of overall EU Hg emissions to air and up to 9–13% of overall EU emissions to surface waters. The estimates of EU Hg emissions to air from crematoria used in this report (based on national reporting) are somewhat higher than the estimates in the 2010 inventory (maximum estimate ca. 1.1 t/y). This may indicate that, for example, the effectiveness of Hg emissions reductions due to control devices at crematoria in Europe has been overestimated in the 2010 inventory. However, this component of emissions to air has acknowledged high uncertainties, and emission factors and methods applied in different countries to estimate crematoria emissions vary considerably.

2.3.3.11 Fate of mercury removed by abatement technologies

Bearing in mind that many assumptions have been made regarding application of APCDs for the different sectors and countries, the results of the 2010 inventory imply that (from the difference between total unabated and abated emissions estimates) almost 3000 t of Hg are removed by currently installed APCDs (including removal by integrated acid plants at non-ferrous metal smelters). This amount does not include Hg removal by processes such as coal washing, or Hg removal by other systems designed to reduce Hg contamination that are not directly linked to air emissions. Control technologies installed at industrial facilities remove Hg that would otherwise be emitted to air. There is little information about the ultimate fate of the Hg removed in this way and about how the Hg-containing wastes are subsequently disposed of. Some of the Hg is recovered and re-enters the market supply, or is stockpiled. Some of the Hg removed by APCDs will be associated with materials such as fly-ash that may be disposed of in landfill or used in production of building materials (plaster board, road surfacing materials, cinder/breeze blocks, etc.). Mercury ‘recycled’ into construction materials is generally considered ‘inert’, however some Hg

will almost certainly be re-emitted or leach into aquatic systems if, for example, landfills are not properly constructed. In general, it can be assumed that these technologies will reduce the amount of Hg that is transported long distances, by concentrating it, at least temporarily, in materials that are disposed of or used within the source regions themselves.

2.3.4 Geospatial distribution of the 2010 inventory

Products of the 2010 global inventory project work include a geospatially distributed (gridded) version of the inventory of anthropogenic Hg emissions to air, for use in modelling and other related applications. The approach used to produce the gridded inventory followed a general methodology used previously and described by Wilson et al. (2006) and AMAP/UNEP (2008), whereby emissions are assigned to point sources where possible, with the remainder being (spatially-) distributed according to the distribution of some appropriate surrogate parameter such as population density; with the combined results then allocated to cells in a 0.5×0.5 degree grid.

Previous work has developed a model for performing this task based on the construction of several ‘distribution masks’ for application to emissions from different sectors. These ‘distribution masks’ were updated in the current work. A recognised deficiency of previous work was the limited extent of the information concerning point source emissions. Allocation of emissions to specific point sources is the most precise way of geo-spatially distributing emissions, in particular those associated with industrial and energy sources; however, point source information in the past has been largely restricted to a few countries for which plant specific pollution release inventories or emissions inventories are available, namely the United States, Canada, Australia, and EU Member States. A major effort under the current work, therefore, has been to extend the point source coverage to other major emitting countries, using new resources and information made available through the project contact group.

Point source data for the different sectors were compiled from a variety of available sources, some comprising national/regional release inventories (as mentioned above) and others based on industry group (web-based) resources or other public domain information resources. These were supplemented with national information where available. The work to prepare a comprehensive register of point sources useable for distributing Hg emissions involves a number of steps, not least of which is filtering or cleaning the information from multiple sources to remove duplicates, and where possible to correct for obvious errors. Many of the available resources are poorly quality-controlled and inconsistent use of, for example, Mt as an abbreviation for mega-tonnes and metric tonnes in relation to plant capacity or fuel use is one of the commonly occurring issues that needed to be addressed (and which can be, based on reasonable assumptions).

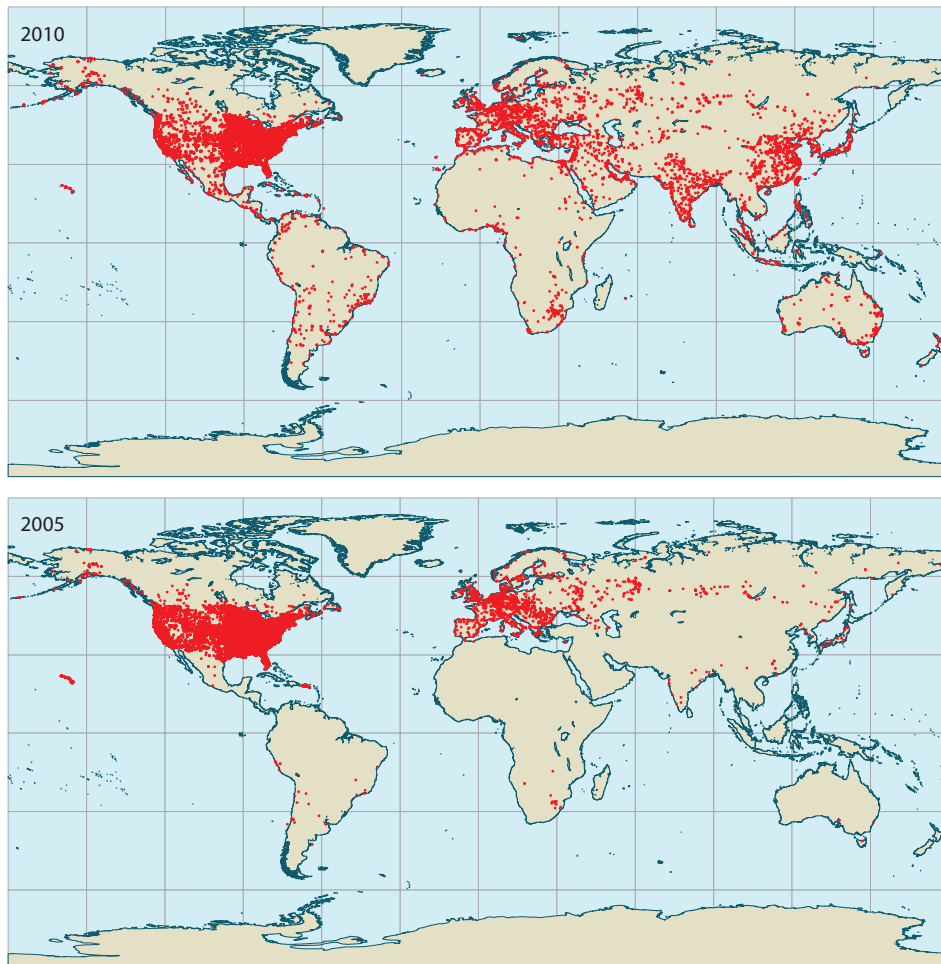


Figure 2.10. Maps showing the increase in the number of mercury point sources utilised in the geospatial distribution of the 2010 global inventory (above) compared with those utilised in the 2005 global inventory (below) spatial distribution work.

Key information required for each point source includes its location, the sector in which it operates (ideally including information on fuel use, etc.), and its associated Hg emission, or some information that can be used to allocate a portion of the total national emission for a given sector to that particular source. In order to apportion (national total) emissions between point sources relevant for the sector concerned the following procedure is followed: (1) In cases where a plant is listed in a national emissions inventory and/or in an official government report which include an applicable (2008–2010) Hg emission, the reported emission value is assigned to that plant. In many cases, however, while basic information concerning a point source is available – Hg emissions data are lacking. Commonly the situation is that some plants within a country have associated emissions, while others do not. In these cases the total national emissions for a given sector – or that part remaining after subtraction of the amount assigned to plants with reported emissions – is distributed between the plants without reported emissions. This is done by (2) weighting the emissions assigned to a given plant by some appropriate factor. Generally this factor is plant capacity – information on which is often available. For plants with no known capacity, an average capacity is calculated from the information for other plants in that country. When neither emission nor capacity is known for any of the plants in a country, the emissions for the sector concerned are distributed evenly between the plants in that country. Any national emissions remaining after

distribution (which can be the case if some point sources lack critical information such as location coordinates) is added to the country's 'diffuse emissions' for the sector and handled by the geospatial distribution model accordingly.

This procedure recognises a number of assumptions, such as the fact that reported plant capacity may not necessarily provide a good indication of a plant's actual operations, however, this information is used in relative rather than absolute terms and the gains using these assumptions are considered preferable to other assumptions that would otherwise be involved in the spatial distribution process.

Figures 2.10 and 2.11 present some of the results of this component of the work.

It is worth noting in this connection that this procedure reveals apparent discrepancies between emissions assigned to point sources in some national/regional pollution release inventories and those allocated on the basis of the national emissions estimates produced in the current work. The implications are either, in some cases, considerable over-estimation of emissions from some sectors in the current work – which is not consistent with the generally good agreement between the estimates produced and those reported in official national inventories – or a considerable under-estimation of point source emissions reported in some pollution release inventories. These discrepancies warrant additional work, but it was beyond the scope of the current project to address this in any detail.

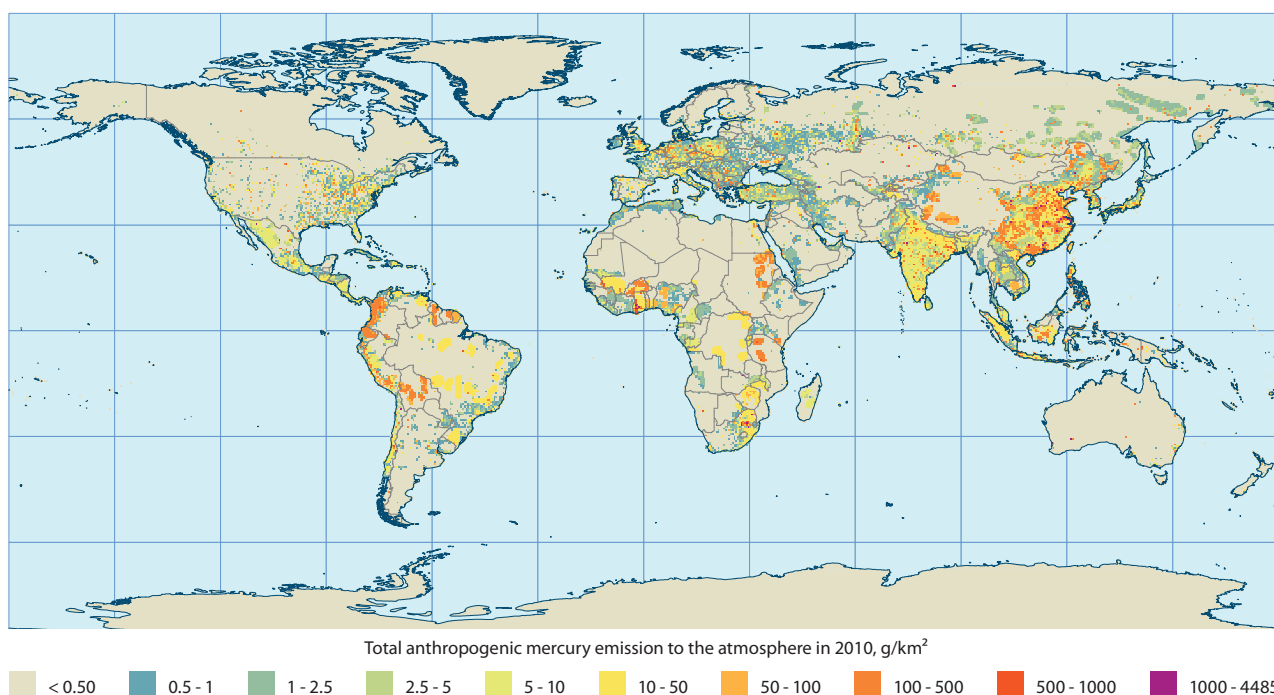


Figure 2.11. The geospatially distributed 2010 global inventory of anthropogenic mercury emissions to air (does not include emissions from contaminated sites).

2.4 Trends in mercury emissions to the atmosphere

2.4.1 Comparing emission inventories over time: Reasons for caution

Owing to the factors described in Section 2.2.2, it is not appropriate to directly compare results from different global inventories prepared at different times using different methods and assumptions. However, this has not prevented such comparisons being made.

Therefore it is relevant at this point to reiterate a KEY MESSAGE: that the emission estimates derived from this work CANNOT be directly compared with those from previous global emission inventories. Such comparisons may be inappropriate and could lead to erroneous conclusions regarding emission trends.

In order to compare global anthropogenic emissions inventories produced between 1990 and 2010 it is necessary to take into account two main issues: changes in the methodology used (including sources of activity data), and the introduction of additional sectors in more recent inventories.

In the past, some tentative comparisons of global anthropogenic emission inventories produced between 1990 and 2005 have been made based on the (somewhat) internally consistent approaches used to produce these inventories. Some tentative comparisons can also be made between 2005 and 2010 results for certain sectors. The following discussion of these comparisons illustrates some of the complicating factors that need to be taken into account when comparing inventories produced at different times.

2.4.2 Trends in emissions 1990–2005

Because the 2005 global inventory introduced major new emissions sectors compared with earlier inventories, an attempt was made to produce a harmonised set of global inventory estimates (1990–2005) by applying the 2005 methodology to the activity data from earlier years, and comparing emissions for a comparable set of emission sectors based on more consistent activity information (AMAP, 2010; UNEP, 2010a). Although this approach is compromised by the fact that it does not address the (possibly) significant changes in (abated) emission factors that would be expected over the period 1990–2005 in some countries (especially in Europe and North America) due to changes in technology, it did address some of the artefacts of different approaches and data components used in constructing past global emission inventories. The results of this work, illustrated in Figure 2.12 and included in

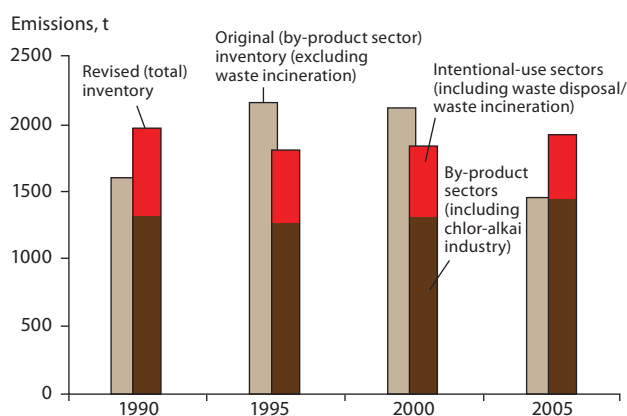


Figure 2.12. Revised estimates of total global anthropogenic mercury emissions to air from by-product and intentional-use sectors for the period 1990–2005, showing the effect of re-calculation using the 2005 methodology. Source: AMAP (2010).

Table 2.9. Comparisons of past and present global anthropogenic mercury emission estimates (in tonnes) produced using different procedures (see also Table 2.10).

	1990	1995	2000	2005	2010
Originally published inventory estimates	1732 ^a	2214 ^a	2190 ^a	1926 ^b	
Inventory estimates revised using 2005 methodology	1967 ^b	1814 ^b	1819 ^b	1921 ^b	
of which ASGM				350	
Inventory estimates produced using 2010 methodology					1960
of which ASGM					727
Coal combustion				462 ^c	474
Cement				133 ^c	173
Pig iron and steel				36.7 ^c	45.5
Non-ferrous metals (Cu, Pb, Zn, Hg)				169 ^c	200
Large-scale gold production				98.3 ^c	97.3
Waste from Hg-containing products				112 ^c	95.5
Other sectors					145 ^d

^a By-product sectors only (plus waste incineration in Europe (EU countries), Canada and the USA; ^b by-product and intentional use sectors (including ASGM) combined (Table modified from AMAP, 2011); ^c estimate produced using 2010 methodology on 2005 activity data from essentially the same sources as those used in 2010; ^d includes sectors not quantified in previous inventories.

Table 2.9 (1990–2005), reveal possible underlying trends in global anthropogenic emissions that are very different from those that would appear to exist if total emissions reported for past global inventories are compared at face value.

2.4.3 Trends in emissions 2005–2010

In a similar manner, it is possible to use the databases developed to prepare the 2010 inventory to ‘simulate’ the emissions that would have been derived using 2005 activity data (for some emission sectors at least). Results for emissions from coal combustion, cement, ferrous, and non-ferrous metal sectors and from wastes from Hg-containing consumer products using this approach are also included in Table 2.9. It is important to note that this ‘simulation’ is based largely on activity data alone and does not take proper account of possible changes in abatement technology from 2005 to 2010. Results for some individual sectors are discussed in more detail in following sections.

When these revised estimates are combined with 2005 estimates for some additional sectors (ASGM, crematoria, and chlor-alkali industry) it is possible to compare 2005 and 2010 results on a more consistent basis. It should be noted that this analysis does not include sectors that were introduced for the first time in 2010; however, the major emission sectors (accounting for some 95% of the total 2010 global inventory) are included. The results shown in Figure 2.13 illustrate the implied changes in emissions between 2005 and 2010 from different sub-regions for three different groups of sectors (representing industrial by-product emission sectors, ASGM and intentional-use and waste sectors, respectively).

One obvious feature in these comparisons is the significant change in the estimates associated with ASGM. In this case however, the difference is not (directly) associated with changes in activity, but rather with changes in reporting and emission evaluation methods, as discussed in Section 2.4.4. This highlights the caution that needs to be applied and the pitfalls associated with superficial comparisons of estimates derived at different times using different methods and data sources.

Notwithstanding the implications of changes in methodology for evaluation of emission trends, the new methodology applied in 2010 is considered to result in more reliable estimates of global anthropogenic Hg emissions, and the new methodology also introduces procedures that should make it possible to better identify and correctly attribute trends in future emissions estimates – avoiding some of the factors that confuse the picture when comparing previous inventories.

2.4.4 Interpreting apparent 2005–2010 trends in emissions – using the example of artisanal and small-scale gold mining

As discussed in the previous section, results presented in the AMAP/UNEP (2008) report and the current report (see Section 2.3.1) imply considerably increased Hg emissions from ASGM from 2005 to 2010; raising the question of what is responsible for this increase?

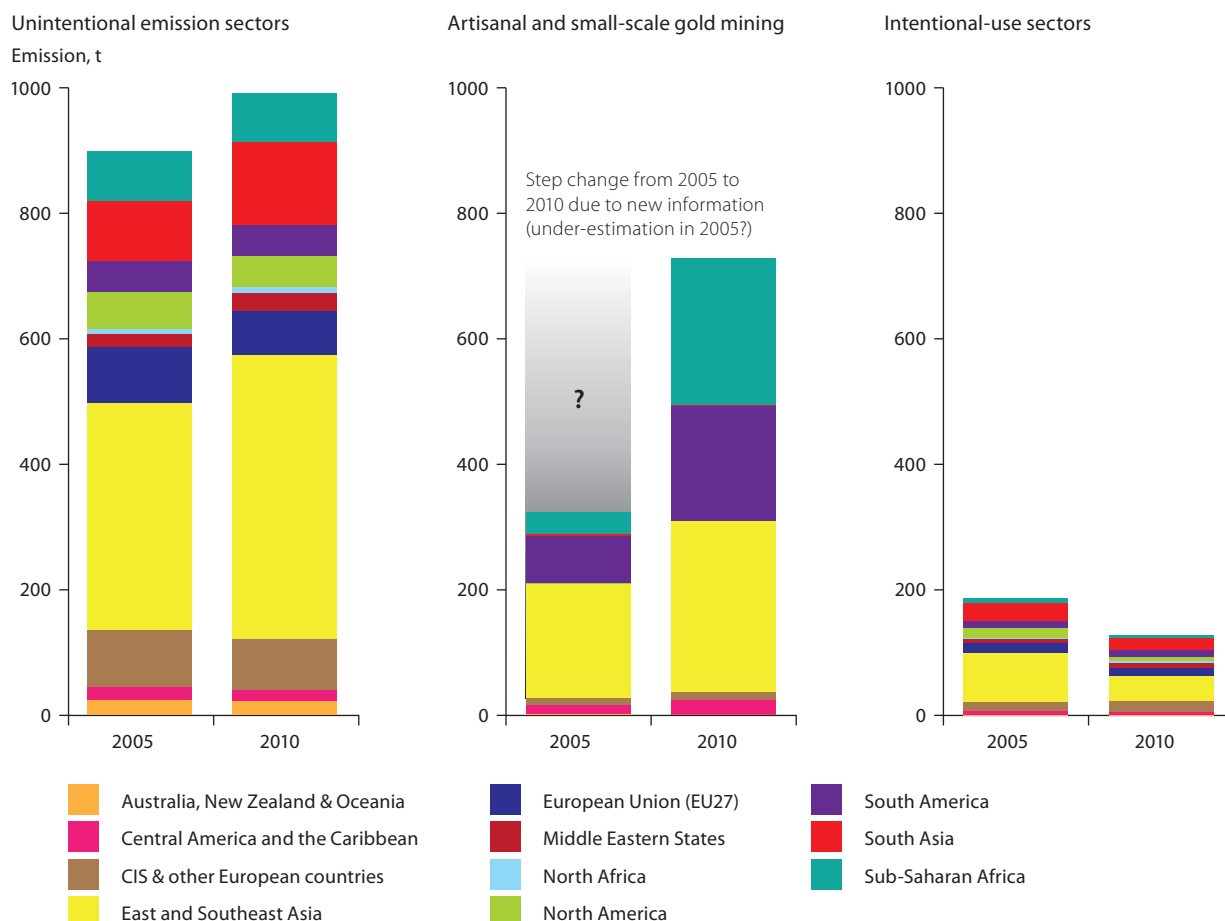


Figure 2.13. Comparison of 2005 and 2010 estimates of emissions to air from different regions, based on application of the 2010 inventory methodology. Unintentional emission sectors: Coal burning, ferrous- and non-ferrous (Au, Cu, Hg, Pb, Zn) metal production, cement production. Intentional-use sectors: Disposal and incineration of product waste, cremation emissions, chlor-alkali industry.

Although it is likely that there was more ASGM taking place in the world in 2011 than in 2008 due to the increased price of gold and increased rural poverty, the increase in the Hg emission estimate presented in the Burkina Faso case study (see Annex 2) is predominantly due to improved reporting. Similarly, the implied increase in global ASGM Hg emissions is also mainly due to more and better data for countries for which the emissions were previously poorly estimated, such as the West African countries which were formerly only reported as having a presence of ASGM and therefore assigned a minimal value of 0.3 t/y. In other words, the baseline has been improved.

2.4.5 Interpreting apparent trends in emissions – other main sectors

One of the most important considerations when evaluating trends in (anthropogenic) emissions is to consider whether these make sense in relation to changes that may be expected based on, for example changes in economic activity, technology, fuels and raw materials or regulations. From the previous discussion, it can be concluded that any 'real' changes from 2005 to 2010 in Hg emissions associated with ASGM activities are likely to be masked by the effects of changes in reporting

and estimation procedures. Such issues need to be given careful consideration in any evaluation of emission trends.

The AMAP (2011) assessment concluded that global Hg emissions to air have been fairly constant since around 1990, but with emissions decreasing in Europe and North America and increasing in Asia. In 2005, East and South East Asia contributed about 50% of global Hg emissions to air from human sources, and there were indications that, after decreasing from a peak in the 1970s, global emissions from human sources may be starting to increase again.

For some of the main anthropogenic emission sectors, emission estimates for 2005 have been re-calculated using the 2010 methodology; applying it to activity data for 2005. It should be noted that these results do not take into account changes in application of emission abatement technology over the period – essentially assuming the abatement technology applied in 2005 was the same as that applied in 2010. It is likely that in some regions (including parts of Asia), some improvements in application of abatement technology were implemented between 2005 and 2010. This would result in some under estimation of the re-calculated 2005 emissions, but (based on sensitivity of estimates to changes in technology profiles) it is not considered likely that this would greatly alter the implied trends.

Table 2.10. Regional emissions (in tonnes) from selected sectors, and changes from 2005–2010 (based on application of 2010 inventory methodology).

	Coal combustion			Cement production			Ferrous metal production		
	2005	2010	% Change	2005	2010	% Change	2005	2010	% Change
Australia, New Zealand & Oceania	3.9	3.6	-8.2	0.7	0.7	0.0	0.04	0.04	0.3
Central America and the Caribbean	10.3	3.5	-65.5	3.3	3.2	-4.1	0.3	0.3	13.2
CIS & other European countries	35.0	26.9	-23.1	4.7	4.7	-1.1	7.8	7.5	-4.6
East and Southeast Asia	182.3	206.3	13.2	72.9	102.4	40.5	18.7	28.2	51.3
EU25	57.5	44.1	-23.4	14.4	13.1	-8.7	3.0	2.5	-17.0
Middle Eastern States	8.0	10.5	30.8	9.3	13.4	43.7	0.4	0.4	23.5
North Africa	1.0	0.5	-53.2	5.8	7.9	35.7	0.1	0.1	-36.1
North America	50.5	43.4	-13.9	3.4	2.3	-33.6	1.5	1.1	-25.0
South America	3.3	2.2	-33.0	3.8	5.1	35.3	3.2	3.0	-3.9
South Asia	70.8	90.8	28.2	11.6	16.9	45.4	1.4	2.0	40.2
Sub-Saharan Africa	39.6	42.6	7.6	2.8	3.4	24.0	0.3	0.3	-15.7
Total	462.2	474.3	2.6	132.7	173.0	30.4	36.7	45.5	24.0

Results and comparisons are tabulated in Table 2.10. These results indicate that emissions from some of the main 'industrial' sectors have increased by up to 30% from 2005 to 2010, but with significant differences between regions, with decreases in some regions and increases in others (Asia in particular). For the waste sectors, trends indicate decreasing emissions in all regions. The possible reasons for some of these developments are discussed below.

2.4.6 Coal combustion

From an overall activity perspective, coal burning continues to increase, especially in China (see Figure 2.14); at the same time, however, improvements are being made in efficiency of energy production, and the application of air pollution control

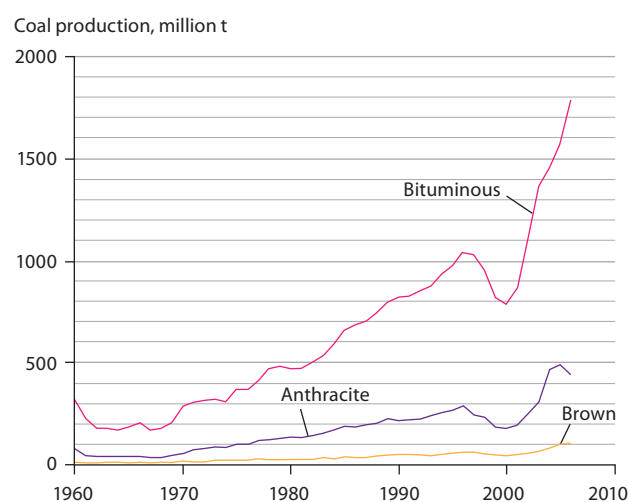


Figure 2.14. Trends in coal production in China. Source: Based on International Energy Agency data.

technology at power plants (including new power plants being constructed in China and in other parts of the world). These improvements are offsetting to a large extent the increase in Hg emissions that would otherwise result from the increase in coal combustion.

In the United States, emissions associated with stationary combustion (mainly coal burning) at electricity generating units have reportedly decreased from ca. 53 t in 2005 to 26.8 t in 2008 (US EPA, 2012). This is partly explained by the installation of Hg controls to comply with state specific rules and voluntary reductions, and the co-benefits of Hg reductions from control devices installed for the reduction of sulphur dioxide and particulate matter as a result of state and federal actions, such as New Source Review enforcement actions (US EPA, 2011a,b). A major factor may also be a change in the source of the coals used, with power plants using more low sulphur coals (with lower Hg content) in order to comply with new air pollution regulations. These documents project that US emissions from this sector will be further reduced by 2016.

2.4.7 Cement production

On the basis of activity data taken from the USGS Minerals Yearbook (USGS, 2012), cement production between 2005 and 2009 increased by almost 30% (Figure 2.15); however with large differences between sub-regions. Production in Europe, Oceania and North and Central America remained stable or declined, whereas in South America, the Middle East, Africa, and in particular Asia production increased. The consistent trends in emissions indicated in Table 2.10 are therefore mainly a reflection of these changes in activity.

Non-ferrous metals (Cu, Pb, Zn, Au, Hg)			Waste (from consumer products)		
2005	2010	% Change	2005	2010	% Change
18.5	16.7	-9.9	0.7	0.7	-0.9
8.3	11.7	40.9	4.0	3.4	-14.3
42.9	42.2	-1.7	8.3	7.1	-13.8
86.5	114.5	32.4	44.7	36.8	-17.8
14.4	11.7	-18.3	6.8	6.0	-12.4
3.8	3.9	0.8	5.2	4.5	-13.0
0.8	0.9	1.0	2.6	2.4	-9.1
3.5	3.2	-6.5	7.6	6.2	-17.7
39.8	38.7	-2.7	8.7	7.6	-13.0
11.3	22.3	96.9	19.0	16.7	-12.1
37.2	31.8	-14.5	4.7	4.2	-9.7
267.1	297.7	11.5	112.1	95.5	-14.8

2.4.8 Ferrous and non-ferrous metals

Emissions from ferrous metal production (also largely reflecting activity data), decreased in Africa, Europe and North America, and to a lesser extent South America, but increased by more than 40% in both South Asia and East and Southeast Asia (Table 2.10).

The trends described in Table 2.10 indicate increases in emissions associated with non-ferrous metal production in East and Southeast Asia and in particular South Asia. In absolute terms the increase in (activity and associated) emissions in East and Southeast Asia is by far the greatest, however in relative terms the increase in South Asia is notable and due largely to production increases in India. In Central America and the Caribbean, the large percentage increase is associated with emissions from large-scale gold production.

2.4.9 Comparing emission trends and observations

Over longer time scales, Hg levels in environmental archive samples such as ice cores have been correlated with emissions of Hg to the environment (see Figure 2.16).

Recent trends in emissions to the atmosphere can also be compared with trends in Hg levels observed at atmospheric background monitoring sites (see Figure 2.17). This graphic illustrates that reliable air monitoring time series began only relatively recently, with little change in global emissions over the period concerned.

Cement production, million t
(ten million t for East and Southeast Asia)

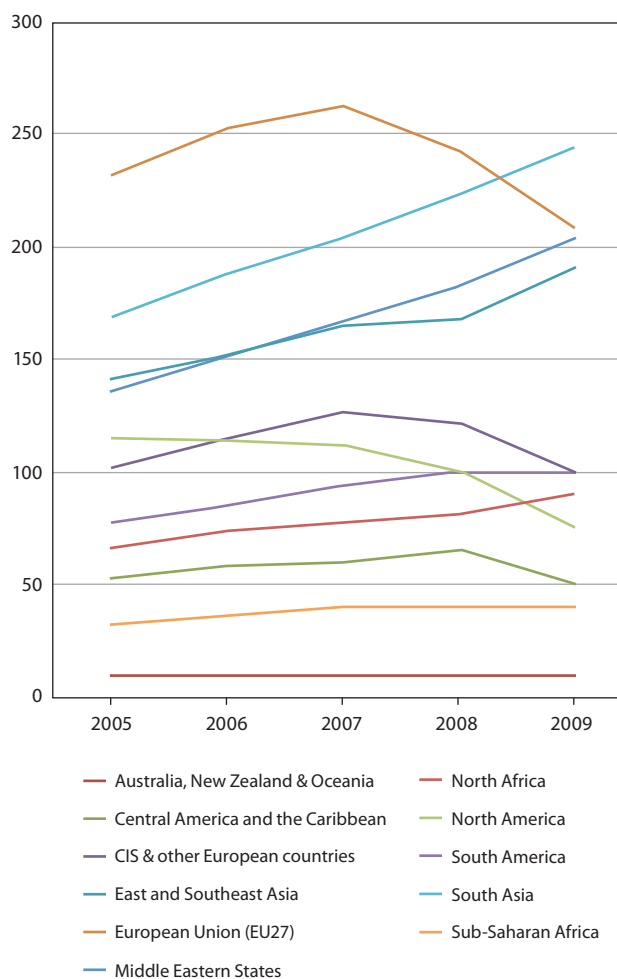


Figure 2.15. Trends in cement production. Note: different units for East and Southeast Asia. Source: United States Geological Survey.

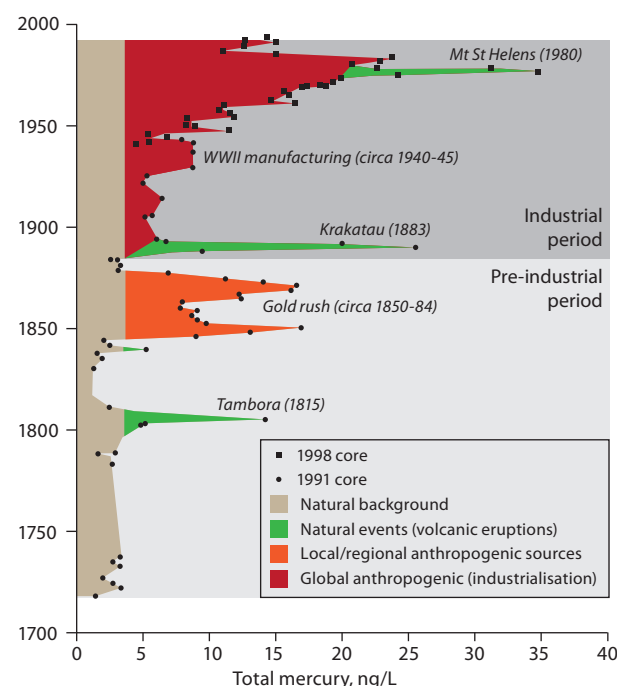


Figure 2.16. Ice core record of deposition from Wyoming, USA. Source: after Schuster et al. (2002).

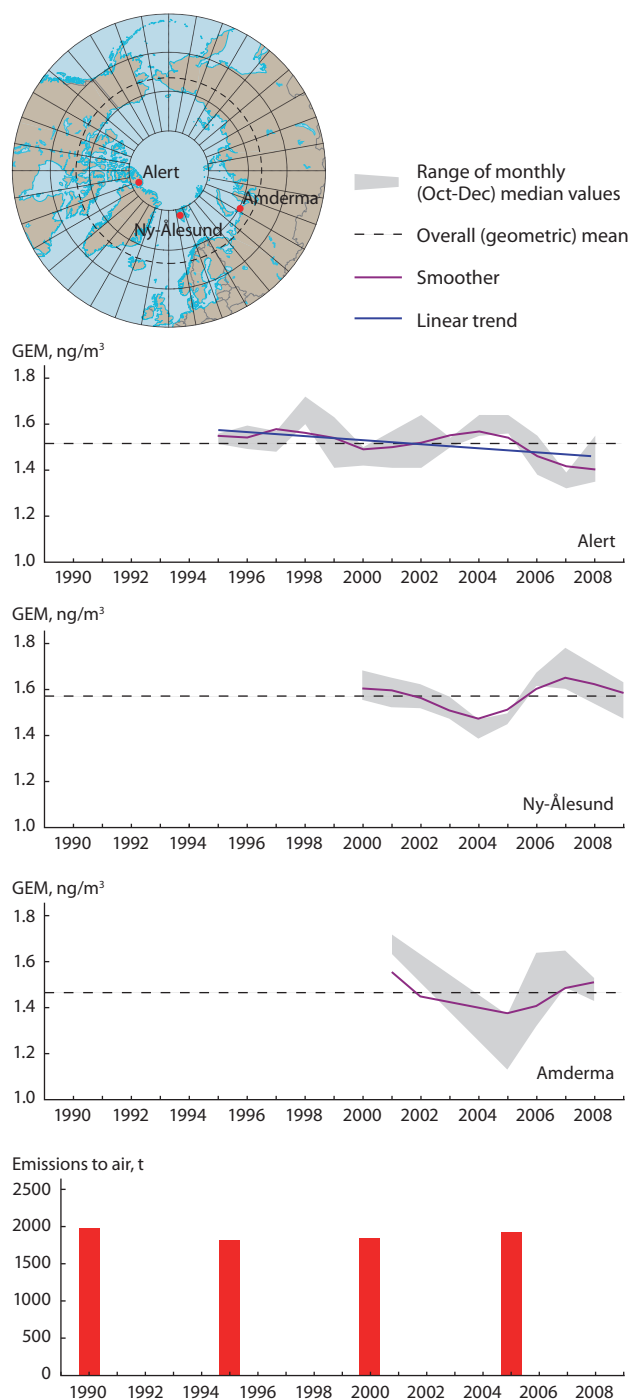


Figure 2.17. Trends in emissions (see Figure 2.12) and observed gaseous elemental mercury concentrations at Arctic background air monitoring sites. Source: after AMAP (2011).

2.4.10 Scenarios and identifying areas for targeting reductions

The 2008 *Global Atmospheric Mercury Assessment: Sources, Emissions and Transport* report (UNEP Chemical Branch, 2008; AMAP/UNEP, 2008) included a first attempt at producing global emissions inventories for future scenarios representing status quo (business as usual), extended emissions control, and maximum feasible technological reduction. At the time this was presented as very provisional work.

Since 2008, additional studies have presented estimates of global Hg emissions based on future scenario projections, for example, Streets et al. (2009) uses four IPCC (Intergovernmental Panel on Climate Change) scenarios of energy growth and technology to project global Hg emissions in 2050 in the range 2390–4860 t, representing a change of -4% to +96% compared to their estimate of 2480 t in 2006.

In addition to suffering from the same limitations as previously discussed concerning universal application of a single (abated) emission factor for a given sector, the scenario inventories presented in the 2008 report were criticised for the fact that they also made generic assumptions regarding the extent to which additional Hg reductions could be achieved within countries in various (continental) regions. That is to say, it was assumed that the same level of (further) Hg emission reductions could be achieved in advanced as well as less advanced countries within a region – despite some advanced countries probably having already largely implemented some of the ‘future’ emission control technologies. In part this reflected the fact that emission inventory systems in the past included very little information on actual implementation of technology in individual countries. Addressing this deficiency was one of the goals of the procedures and database systems established to produce the 2010 inventory.

Using the new database methodologies it should now be possible to implement scenarios involving both activity and technology components – that is, effects of economic development and fuel mix projections, etc. on activity levels, combined with effects of realistic projections on implementation of additional Hg emission controls to those currently in use – at an individual country level.

It has not yet been possible to complete new work on scenario emission inventory estimates based on use of the databases established to support the production of the 2010 emissions inventory – however this work is currently planned as part of the GMOS (Global Mercury Observation System) project work (see Section 3.3.5 for more details).

This includes possible use of the databases that have been constructed by countries to investigate the changes in calculated national emissions that would result from implementing different strategies, for example, by adjustment of their applied technological profiles, or changes in raw materials.

The economic crisis of 2008 led to stagnation and decreased economic activity in much of the world post-2008; with notable exceptions in some Asian countries and countries in parts of South America. However, even in the countries with continuing growth, this was lower than anticipated at the time the scenarios presented in the AMAP/UNEP (2008) report were prepared. The stagnation of economic development in a number of regions of the world is reflected in activity data for several Hg emission sectors related to energy and industry and this is in turn reflected to some extent in emission trends from 2005 to 2010.

2.5 Conclusions

2.5.1 Key findings on global emissions of mercury to the atmosphere

A new improved methodology has been developed to prepare an inventory of Hg emissions to air from anthropogenic sources in 2010 that allows better characterisation of differences between countries in terms of fuels and raw materials used and technologies and practices applied. Applying this methodology in a consistent manner globally results in an estimate of anthropogenic emissions to air in 2010 of 1960 metric tonnes (range 1000–4070 t).

Emissions estimates, whatever their basis, have large associated uncertainties; this remains the case despite the considerable progress that has been made in recent years in improving the knowledge base available for the development of emissions factors, etc. Quantifying uncertainties is difficult in light of the numerous assumptions involved in any estimation process. Crude estimates of uncertainties indicate that these can be from ca. $\pm 30\%$ to more than an order of magnitude, depending on the sector/country concerned. Low- and high-range values associated with the 2010 global inventory reflect these uncertainties and are intentionally wide to reflect the still poor state of knowledge about some key factors involved in estimating Hg emissions.

The main sectors identified as sources of anthropogenic emissions to air in 2010 are artisanal and small-scale gold mining (ASGM), coal combustion, production of ferrous (iron and steel) and non-ferrous metals (including copper, lead, zinc, aluminium and large-scale gold production), and cement production. Other important sectors include incineration and disposal of wastes from consumer products containing Hg, emissions from contaminated sites, chlor-alkali industry emissions, oil refinery emissions, emissions from combustion of oil and natural gas, and from human cremation (associated with use of Hg in dentistry).

The 2010 emissions inventory covers most of the major anthropogenic sources of emissions to air, and includes some sectors not previously quantified. However, there remain potentially important sources that are still not yet quantified in the inventory. These include: use of Hg in vinyl-chloride monomer production; emissions from secondary metals production and ferro-alloys; oil and gas extraction, transport and processing other than refinery emissions; production and combustion of biofuels; emissions from industrial and some hazardous waste incineration and disposal; emissions from sewage sludge incineration; emissions during preparation of dental amalgam fillings and disposal of removed fillings containing Hg.

The sectors responsible for most emissions to air are the same as those previously identified; however, the estimated emissions associated with ASGM are significantly higher than previously estimated. This is attributed mainly to new

information on use of Hg in ASGM in certain regions, in particular Sub-Saharan Africa. The implication is that emissions from ASGM may have been under-estimated in 2005. Due to the largely unregulated and in some cases illegal nature of ASGM, the associated emissions estimates are very uncertain and should be treated accordingly. Observational and measurement data to confirm high releases in areas of ASGM are lacking and represent a gap that should be filled.

The increase in emission estimates for ASGM has altered the proportional contribution of different sectors to the total global anthropogenic emissions compared with those presented in the AMAP/UNEP (2008) assessment; however, although fossil fuel (mainly coal) combustion emissions have decreased from ca. 45% (2005) to ca. 25% (2010), in absolute terms the emissions associated with coal combustion from major use in power plants and industry have remained fairly stable and may have increased slightly between 2005 and 2010. Emissions estimates for other coal uses, including domestic and residential coal burning, indicate these may have been over-estimated in previous inventories, due largely to assumptions regarding the relative amounts of coal burned in the power vs. domestic/residential sectors in some countries.

The major source region for anthropogenic emissions to air continues to be East and Southeast Asia (ca. 40% of the global total) with South Asia contributing a further 8%. The percentage contributions from South America and Sub-Saharan Africa are increased due to the increased estimates of emissions from ASGM.

Any evaluation of trends in emissions needs to take account of artefacts that can arise from changes in reporting and methods used to produce inventory estimates. Changes in methods and data and information sources and the introduction of additional sectors invalidate direct comparison of the results of global emission inventories produced over the past 25 years. Preliminary attempts to re-calculate emissions in 2005 using components of the new methodology allow some comparisons to be made of changes in emissions from 2005 to 2010. The results indicate that summed emissions from largely industrial sectors (fossil fuel combustion, metal and cement production) are continuing to increase while emissions from some other sectors (such as the chlor-alkali industry) continue to decline.

Examination of environmental archives indicates that anthropogenic Hg emissions are likely to have peaked around the late 1970s. Comparisons of emission trends since 1990, based on rescaling emission inventories for the period 1990–2005, gives some indication that anthropogenic Hg emissions to air, although generally stable at around 2000 t/y may be increasing slightly again, with decreases in emissions in some regions (e.g., Europe and North America) being offset by increases in others (in particular Asia). Results of the 2010 inventory do not contradict this possibility. The implied changes in emissions reflect in general terms the patterns of regional economic development during the period from 2005 to 2010, with continued economic growth in, in particular Asia and stagnation (following the 2008

economic crisis) in much of Europe and North America. The global economic crisis during the latter part of the past decade has resulted in emissions in some regions decreasing more, or increasing less than anticipated in scenarios presented in the 2008 assessment (AMAP/UNEP, 2008).

Trends in atmospheric Hg levels measured at some background sites where relatively long-time series exist (e.g., Alert in northern Canada, Amderma in northern Russia, and Mace Head in western Ireland) show generally decreasing levels of atmospheric Hg, although this is not observed at some other sites (e.g., Ny-Ålesund on Svalbard). Monitoring site location in relation to major emission source regions and time lags in possible environmental response to changes in emissions may be important factors that need to be taken into account when interpreting trend results at monitoring sites.

Estimates obtained using the global methodology generally show good agreement with national estimates, in some cases produced using very different approaches, on a national total basis. Agreement for individual sectors was more variable, in particular in the case of comparisons with the LRTAP based estimates, however many of these discrepancies can be attributed to differences in the way emission sectors are categorised, specified and employed in reporting under different systems. Comparisons were made with national inventories provided by several countries (Australia, Canada, Japan, Korea, Mexico and the United States, and European countries reporting to the LRTAP Convention). The results of these comparisons lend a degree of confidence to the generic assumptions applied, at least for some of the country-groups. The level of agreement is best for those countries that routinely produce their own detailed emission inventories, and where the information base is correspondingly most comprehensive. It was not possible to make direct comparisons with emission inventories developed using the UNEP Toolkit because many of these inventories refer to different years with different corresponding activity data, and/or were developed using default emission factors that are being revised based on information acquired during the preparation of the 2010 global inventory.

If reporting systems are to be compared, they need to be more specific and better aligned in terms of the sources that need to be distinguished.

National emissions estimates from some countries based on individual facility reporting and site measurements should be more accurate than those based on the global inventory methodology. However, this is difficult to evaluate as most nationally reported inventories lack estimation of associated uncertainties. It is also important to recognise that many measurement-based estimates are derived from relatively few measurements covering short periods that are then extrapolated to produce annual emissions. It is therefore important that such reporting is subject to validation and that associated uncertainties are quantified. In general, an evaluation and quantification of uncertainties should be a routine component of emissions reporting systems.

The contributions from experts from a number of countries, and discussion of discrepancies between the global estimates and estimates from national and industry sources proved an essential part of the work to prepare the global emissions inventory, and significantly improved the methodology. The results of these discussions are in turn being used to inform the work to revise and update the UNEP Toolkit for identification and quantification of Hg releases.

The 2010 estimate of emissions to air from anthropogenic sources is consistent with the values used in global models that attempt to represent global Hg cycling and global Hg budgets. According to these models, current anthropogenic sources contribute ca. 30% of total annual emissions to air; natural sources contribute about 10% of annual emissions to air. Re-emissions from soils and surface waters contribute the remainder. Re-emissions are the result of environmental accumulation of Hg from past releases to air, land and water. Given that anthropogenic emissions have been larger than natural emissions since the start of the industrial age, the bulk of re-emitted Hg is from historical anthropogenic sources. Reducing current anthropogenic emissions and releases of Hg will eventually reduce the pool of Hg that is cycling in the environment and therefore reduce future re-emissions. Estimated impacts of anthropogenic emissions reductions generally do not account for the concomitant benefit in resulting reductions of re-emitted Hg from legacy pools and, thus, understate impact of future emission controls.

One consequence of the large reservoirs of Hg already in the environment is that there is likely to be a time lag of years or perhaps decades, depending on the reservoir, before emissions reductions have a demonstrable effect on Hg levels in human food chains. This is particularly likely for Hg levels in marine food chains. This reinforces the need to continue and strengthen international efforts to reduce current Hg emissions and releases, as delays in action now will inevitably lead to slower noticeable recovery of the world's ecosystems from Hg contamination.

Substantial amounts of Hg are 'captured' during industrial operations or by air pollution control devices. Some of this Hg is recovered and enters the Hg supply or is removed to long-term storage. However, large quantities of Hg are retained in materials that are used in products, including construction materials, or disposed of in landfill. It is generally assumed that most of the Hg thus 'disposed of' is in an 'inert' form and effectively removed from the environmental Hg cycle. However, information (including measurements) regarding potential re-emissions or releases of Hg from, for example, landfills – especially uncontrolled landfills – is sparse. This issue may warrant further attention, especially in the light of possible effects of climate change on Hg (re-)cycling in the environment.

The structured databases produced to calculate the 2010 global emissions estimates and to maintain and document the data behind these estimates can provide a useful tool for investigating future emissions scenarios. The greater transparency they provide should also allow better

comparisons to be made between the current inventory and future such inventories as data and methodologies are further developed and improved.

The approach used to produce the 2010 inventory estimates has a number of significant improvements on that used in the past. In addition to refining the methodology, the development of structured databases also provides greater transparency. The databases could be used in the future to continue to maintain and document data used to produce inventory estimates, and potentially to develop scenario emissions inventories. They could also provide a complement to the UNEP Toolkit when it comes to estimating and documenting trends in national emissions.

Countries also need to develop the information that is necessary to produce reliable national emission and release estimates for Hg. In this connection, the UNEP Toolkit needs to be updated and kept under continual review to incorporate new information concerning Hg content of fuels and raw materials and changes in technology that can have a major influence on emission factors and output scenarios used in calculating emissions.

The technical developments (databases and underlying data compilations, including the information compiled in Annex 6) that support the 2010 inventory are considered to be significant advances that can also be used to support future emissions inventories. No less of a development is the expert network that has been established to support the work, some elements of which could become the nuclei of future regional expert groups, for South/Central America and East Asia in particular. These networks should be maintained and further extended if at all possible.

2.5.2 Future needs/gaps in information

Improving estimates of global anthropogenic Hg emissions, and reducing uncertainties associated with these estimates requires improved information on a number of relevant subjects. Some priorities in this respect are indicated below:

- Information regarding the application of technology, both industrial processes employed and technology applied to reduce emissions of Hg (and other air pollutants) in different industries and more importantly in different countries.
- Information regarding changes in fuels used in some emission sectors, including sources and characteristics of coal burned in power generation, and alternative fuels (including co-incinerated wastes) used in the cement industry needs to be updated in order to provide robust estimates for emissions from these sectors.
- Measurement data from areas of ASGM activities. The high Hg emissions and releases associated with ASGM are not supported at present by results from field monitoring. If high Hg releases in areas where ASGM is practised are confirmed by observational and measurement data, this would increase the level of confidence in the assumptions regarding Hg emissions and releases from this sector; however such monitoring is currently lacking.
- Information to fill gaps that would allow estimates to be made for potentially important sectors not yet included in the global inventory. These include emissions from use of Hg in VCM production, emissions from secondary metals production and ferro-alloys, oil and gas extraction, transport and processing other than refinery emissions, production and combustion of biofuels, emissions from industrial and some hazardous waste incineration and disposal, emissions from sewage sludge incineration, emissions during preparation of dental amalgam fillings and disposal of removed fillings containing Hg.
- An explanation for the relatively high emissions from secondary ferrous metal production in some countries relative to primary metal production warrants further investigation.
- Improved access to information. Some important information that could assist in further improving estimates and reducing uncertainties is not currently publicly available. This includes information on Hg content of ores and concentrates used in non-ferrous metal production, and additional information regarding Hg sources and fate in the oil and gas sector. Improved cooperation with organisations that have access to such information, including industry sources, could help meet some of these needs.
- Work to allow emissions estimates compiled and reported under different reporting systems (including national release inventories) to be reliably compared, or at least to identify the main areas that currently prevent such comparisons. This work would be essential if future (UNEP) reporting systems are to make use of existing national and other reporting systems.

3. Atmospheric Pathways, Transport and Fate

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3.1 Introduction

The aim of this chapter is to provide an up-to-date overview of the major processes and mechanisms affecting the dynamics of mercury in the atmosphere and at the interfaces with other ecosystems. Understanding of Hg transformations in the atmosphere and major removal processes are dealt with in Section 3.2. Sections 3.3, 3.4 and 3.5 detail the measurements that have been made and compile the available information. The results of current modelling efforts towards an understanding of atmospheric processes at regional and global scales are detailed in Sections 3.6 and 3.7. The chapter concludes with a list of new findings on atmospheric pathways, transport and fate and an overview of research gaps and areas for future studies (Section 3.8).

Specifically, this chapter highlights recent key findings on:

- Major chemical transformations that may influence Hg transport and deposition to and/or evasion from aquatic and terrestrial ecosystems.
- Spatial and temporal variations in Hg and its compounds at ground-based sites, at different altitudes and latitudes, with reference to existing monitoring network programmes at national, regional and global scales.
- Recent advances in monitoring and analytical techniques currently used to measure Hg and its species in the atmosphere.
- Regional and global-scale atmospheric Hg models adopted to assess spatial and temporal distributions of Hg in ambient air and deposition to aquatic and terrestrial receptors for different emission scenarios.

3.2 Atmospheric chemistry

3.2.1 Speciation of emissions

Gaseous elemental mercury (GEM) is by far the most common form of Hg in the atmosphere. This is in part because the major component of anthropogenic Hg emissions is GEM, and also because natural Hg emissions (from terrestrial and oceanic surfaces) are almost exclusively GEM. A further reason for the predominance of GEM over other Hg species

in the atmosphere is that GEM reacts relatively slowly with common atmospheric oxidants such as ozone (O_3), and although it reacts faster with radicals such as OH and Br (or BrO) the concentrations of these in the troposphere are so low that GEM has an atmospheric lifetime of several months to a year. This is not to say that the oxidation of GEM is unimportant in the atmosphere; however, the physical properties of GEM and in particular its volatility mean that very little if any GEM is deposited to the earth's surface. Mercury deposition to terrestrial and marine ecosystems is dominated by oxidised Hg compounds (gaseous oxidised mercury, GOM; or oxidised Hg attached to particles), both via the direct deposition of gas phase species and through wet deposition of oxidised Hg compounds in precipitation.

3.2.2 Atmospheric oxidation and reduction

Mercury can undergo oxidation in the atmosphere both in the gas and aqueous phases. In the gas phase the most important oxidants are believed to be O_3 , OH and Br/BrO, while in the aqueous phase they are O_3 and OH, the concentrations of Br compounds in the atmospheric aqueous phase (cloud and rain droplets) are extremely low. Sea salt aerosol has higher concentrations of halogen compounds, however their total volume is very small compared to cloud droplets. The expression, 'are believed', has been used above quite deliberately because there is still some debate over which oxidant is the most important and even whether the compounds listed above really do oxidise Hg under atmospheric conditions. A debate over which compounds oxidise GEM in the atmosphere has been underway for a number of years; between 2006 and 2008 a series of articles entitled 'Scientific uncertainties in atmospheric mercury models' was published (Lin et al., 2006, 2007; Pongprueksa et al., 2008), the subject was reviewed again in 2009 (see Ariya et al., 2009 and Hynes et al., 2009), and a two part review has recently been published entitled 'A review of the sources of uncertainties in atmospheric mercury modelling' (Subir et al., 2011, 2012). Because the current methods used to detect GOM⁹ compounds in the atmosphere require the reduction of GOM to GEM to allow detection at the very low concentrations found in the atmosphere, there is no experimental evidence of precisely which Hg compounds are comprised in the total GOM.

Global, regional and box modelling studies have been used recently in an attempt to constrain the oxidation rate of GEM in the atmosphere by comparison with observations. Holmes et al. (2010a) investigated the possibility that Br-containing compounds were the sole atmospheric oxidants of GEM using a global model, and found that their results were compatible with observations. Sprovieri et al. (2010) used GOM and GEM data obtained in the Mediterranean marine boundary layer (MBL) to examine the capacity of published

⁹ During the last five years the term GOM (Gaseous Oxidized Mercury) has replaced RGM (Reactive Gaseous Mercury).

rate constants for the reactions of GOM with O_3 , OH or Br compounds to account for the observations. Hedgecock et al. (2008) used a box model to assess the published GEM + Br rate constant values with measurements of GEM and GOM obtained during an atmospheric mercury depletion event. The atmospheric lifetime of GEM in the atmosphere has come under scrutiny owing to the possibility that Br is the major atmospheric oxidant of GEM. A modelling study by Hedgecock and Pirrone (2004) suggested that as a result of the release of reactive halogen-containing compounds from sea salt aerosol in the MBL the cycling of Hg over the oceans could be rapid, and the lifetime of GEM of the order of days under certain conditions. The reduction of deposited GOM and the re-emission of GEM from the sea surface would maintain the relatively constant GEM concentration. Holmes et al. (2009) also found a lifetime of a number of days in the MBL in their modelling study and suggested that the major sink for GOM was scavenging and subsequent deposition of the marine aerosol. Recently, Obrist et al. (2011) observed some of the highest measured concentrations of GOM near the Dead Sea, they provide compelling evidence that the GEM oxidants responsible are Br-containing compounds, and at high temperatures. It is now clear that GEM oxidation by Br-containing compounds is occurring at all latitudes, and not just at the low temperatures found in the Arctic as Obrist et al. (2011) observed GEM oxidation at temperatures up to 45 °C in the Dead Sea region.

These studies indicate that Br and Br-containing compounds are valid possibilities for the role of major atmospheric GEM oxidant. A large number of models continue to use O_3 /OH as the atmospheric oxidants of GOM, not least because the sources and fate of atmospheric Br-containing compounds is not well known.

Gaseous oxidised mercury can be reduced in the atmosphere, and it is believed that this occurs mostly in the aqueous phase via the decomposition of $HgSO_3$, or as has been suggested, via a two-step mechanism involving HO_2 (for all $HgII$ compounds), although the possibility that the HgI intermediate formed is very rapidly re-oxidised by dissolved O_2 has led some authors to doubt the validity of the mechanism under typical atmospheric conditions. It is known that $Hg(OH)_2$ is reduced photolytically to GEM, however this reaction is too slow to be of atmospheric importance (Gårdfeldt and Jonsson, 2003).

Recently, due to a combination of the ever increasing number of monitoring initiatives, field studies and modelling investigations it has become possible to gain an insight into the balance between Hg oxidation and reduction in the atmosphere. This has led some authors to suggest that there may be gas phase reduction reactions occurring in the atmosphere. One suggestion that was made but which is difficult to demonstrate or infer from data is the reaction between GOM and CO (Pongprueksa et al., 2008). Another suggestion which has gained prevalence over recent years and which appears to be supported by experimental evidence

is that Hg can be reduced by SO_2 in the atmosphere. Some observations suggest that the proportion of GOM to GEM downwind of large industrial installations, in particular coal-fired power plants, is – in some cases – not as high as would be expected from measurements performed at the stack. This has led some authors to suggest that the concentrations of SO_2 in these plumes are high enough to reduce an appreciable fraction of the GOM originally present at the exit of the stack (Lohman et al., 2006). This hypothesis has recently been tested using modelling studies in which the ratio of GOM to GEM in the power plant plumes is reduced (Zhang et al., 2012a). Zhang et al. (2012a) in fact found that their modelling results matched the observations more closely if the GOM content of the plume was lower. This effect has however not been observed in other studies where the power plant plumes have been the focus of the study, such as those by Kolker et al. (2010) and Gustin et al. (2012). The gas phase reaction of $Hg + SO_2$ has never been observed in the laboratory and has been inferred from observations and modelling only, but it is a good example of the uncertainty which still surrounds the question of atmospheric Hg oxidation and reduction.

The questions still unanswered concerning the oxidation of GEM do not stop with the incomplete knowledge of the oxidants and rates of reaction. When GEM is oxidised the products of the oxidation process are not known, in fact whether the products are in the gas or solid phase is still under debate. The reviews cited previously and a recent study by Amos et al. (2012) give an idea of the problems involved, which as previously mentioned derives at least partly from the current techniques used to sample and subsequently detect oxidised Hg compounds.

3.2.3 Mercury at environmental interfaces

There are several processes which occur at ecosystem and phase interfaces which can oxidise or reduce Hg. They occur at the interfaces between the atmosphere and lake, ocean (marine), snow, soil, vegetation and atmospheric aerosol surfaces, mostly as a result of photolytic processes, although thermal and biological processes also play a role. These reactions are often followed or accompanied by the exchange of Hg from one environmental compartment to another. For instance GOM which is reduced (probably) by sunlight in the surface layer of the ocean is usually subsequently emitted to the atmosphere as GEM. However, in most instances the details of the chemico-physical processes occurring are poorly understood and difficult to quantify.

One example of rapid Hg deposition and re-emission is the phenomenon known as an 'atmospheric mercury depletion event' (AMDE). These events occur in polar regions around the polar dawn during which significant amounts of reactive Br-containing compounds are released to the atmosphere. These compounds react with both O_3 and GEM and can locally decrease their concentrations to below the instrumental

detection limits. This phenomenon has been studied in several polar regions by a number of research teams over the last ten to fifteen years, the possible impact of a significant flux of Hg to a pristine and fragile ecosystem having caused concern when it was discovered. However it seems that although the deposition flux of GOM can be high over short periods, a large fraction if not all of the GOM deposited to the snow surface is subsequently re-released to the atmosphere, as GEM, after being photolytically reduced.

The oxidation, deposition, reduction and re-emission of Hg during AMDEs is probably the most studied of the atmosphere/surface interactions involving Hg, and although the oxidation and deposition component is mostly understood, the processes involved in reduction and re-emission are less clear. See Chapters 14 (Hynes et al., 2009) and 15 (Ariya et al., 2009) of the technical report of the UNEP-MFTP (Pirrone and Mason, 2009), and Subir et al. (2012) for a more detailed discussion of the current understanding of Hg chemistry at atmospheric interfaces.

3.2.4 Overview of atmospheric mercury dynamics

It is impossible to understand the redistribution of atmospheric Hg emissions and their subsequent deposition around the globe without recourse to modelling tools and studies. Although it is possible to measure emissions at Hg sources, and Hg species concentrations in the air almost anywhere in the world (although this has not happened so far), the link between sources, measured concentration fields and measured deposition fluxes can only be clarified using chemical transport models that simulate the chemistry and dynamics of the atmosphere. Because the speciation of atmospheric Hg is the determining factor for its atmospheric lifetime, when modelling the transport and deposition of Hg it is necessary to have a good understanding of the nature of Hg emissions. It is equally important that the chemistry of the atmosphere is accurately represented in terms of the potential oxidants of Hg. As discussed later in this chapter atmospheric Hg models are generally divided into two categories by scale, either global or regional, where regional could however cover scales as large as the North American continent, Europe or the Mediterranean Basin, for example. Global scale models are required because of the lifetime of atmospheric GEM, which is transported between continents, but which necessarily use a relatively coarse resolution. They are nonetheless capable of identifying major atmospheric transport pathways. A number of studies have investigated the sources of Hg in the Arctic, identifying in particular Europe and North America as the most important source regions, and establishing their relative importance at different times of the year and as a function of major climatological indices (such as the North Atlantic Oscillation) which influence atmospheric transport on very large scales. The outflow of atmospheric pollution in general from southern and South-East Asia has also been studied

and modelling and experimental studies have shown that transport from these regions influences GEM concentrations on the U.S. west coast. Transport from the U.S. east coast has been shown to influence pollutant levels (including Hg) over Western Europe.

Regional models on the other hand employ finer spatial resolution and can be used to investigate more specific source areas, even to the point of individual industrial areas, and to assess their impact on local and regional Hg deposition. It should be reiterated that knowledge of the speciation of Hg emissions is of paramount importance in these studies. In particular, the ratio of GOM to GEM will have a major impact on deposition within a radius defined by a few days dispersion, clearly local meteorology plays an important role, in the eventual deposition distribution. There has been some discussion recently not only of the speciation of emissions but also of the influence that 'in-plume' chemistry may have on the effective emissions from a given source, see Section 3.2.1.

Recently it has been acknowledged by the atmospheric Hg modelling community that it is not feasible to use regional models without input from global models. The transport from southern Asia to the U.S. west coast, from North America to Europe and from almost everywhere in the northern hemisphere to the Arctic at some time of the year, mean that knowledge of how the Hg species concentrations change in space and time at the boundaries of the regional modelling domain is crucial to the success of the study. However, combining global model output with a regional model can lead to inconsistencies. All models use parameterisations to describe the various aspects of atmospheric physics and chemistry, and if they are dissimilar between the global and regional models this can lead to inconsistent results. A model intercomparison using three different global and three regional models was performed by Bullock et al. (2009) who demonstrated the importance of the boundary conditions in regional simulations and showed this to be true for a region as large as the continental United States.

One of the biggest difficulties faced when modelling the emission transport and deposition of Hg, besides the uncertainty in the atmospheric chemistry of Hg, and the difficulties inherent in modelling atmospheric dynamics is the lack of measurement data with which to compare results. There is a particular lack of long-term monitoring data; there are very few places where GOM is monitored, and the southern hemisphere has almost no monitoring data at all. However, this situation has begun to change in the last year or so due to the GMOS (Global Mercury Observation System) project, which should enable models to be refined. With greater confidence in model performance it will be possible to begin investigating the changes in atmospheric Hg cycling which may occur under a changing climate, and to assess with more confidence the consequences of global and regional emission reductions on Hg deposition fluxes.

Only in the last four or five years has there been much progress in the multi-compartment modelling of Hg. While this is not strictly 'atmospheric mercury chemistry', the advances made in linking atmospheric to ocean and terrestrial models is important in understanding the atmospheric Hg cycle, and very importantly, these models are beginning to identify the links between atmospheric Hg deposition and the impact of Hg on the environment, that is, MeHg in the food web. Previously, multi-compartment models estimated the loadings of Hg in environmental compartments, the rate of exchange of Hg between them and attempted to balance the global Hg budget. These models are now becoming more complex and while still using parameterisations for a number of processes, they combine dynamic descriptions of the atmosphere, the upper part of the ocean and parts of the lithosphere (Selin et al., 2008; Sunderland et al., 2009; Smith-Downey et al., 2010). There is mounting evidence to support the idea that much of the MeHg found in biota has its origin in the *in situ* methylation of Hg in the water column, and the most important source of Hg to the world oceans is deposition from the atmosphere. It has been suggested that there is possibly a linear relationship between the inorganic Hg concentration in the ocean and the amount of MeHg formed in the upper waters of the ocean (Mason et al., 2012). For a more detailed discussion, see Chapter 5. Atmospheric deposition of Hg to the oceans (and land) depends on atmospheric Hg oxidation. Hence the need for more atmospheric Hg monitoring and more laboratory studies in order to elucidate the processes occurring in the atmosphere.

3.3 Monitoring networks and programmes around the world

In the past two decades, coordinated monitoring networks and long-term monitoring sites have been established in a number of regions and countries for the measurement of Hg in ambient air and wet deposition. Both Europe and North America have multiple sites with high quality continuous monitoring of Hg in air and wet deposition for more than 15 years. In addition, the High Arctic has been an area of active, continuous Hg monitoring. Notable areas with shorter, yet also high quality continuous Hg air monitoring sites can be found in the East Asian countries and South Africa. Regions with few or no records of high quality, continuous Hg monitoring sites include southern Asia, Africa, South America and Australia. International efforts are now underway to establish long-term monitoring sites with expanded global coverage.

Monitoring of ambient air Hg is focused on the three primary forms of Hg in the atmosphere: GEM, GOM, and particulate bound mercury (PBM_{2.5}, particle diameter <2.5 µm). The concentration of Hg and Hg compounds in ambient air is in the parts per quadrillion range, by volume (ppqv). Typically the range is reported in the literature as 0.01–10 ng/m³ (~1–1000 ppqv). The measurement of atmospheric GEM

is routine, robust and can be easily implemented due to its relatively high concentration and chemical stability. In contrast, measurements of the atmospheric Hg species GOM and PBM_{2.5} are more challenging and uncertain due to their extremely low concentrations and chemical instability. Although average GOM and PBM_{2.5} concentrations are commonly <1 ppqv (<10 pg/m³), these trace species are integral to the processing of atmospheric Hg, and therefore measurements of GOM and PBM_{2.5} are critical to help define and model the fate and transport of atmospheric Hg.

The low concentration of Hg in ambient air has led research and monitoring networks to choose gold-trap pre-concentration and cold vapour atomic fluorescence spectroscopy (CVAFS) detection as the dominant measurement technique (Ebinghaus et al., 2009). The use of cold vapour atomic absorption spectroscopy (CVAAS) is an alternative measurement technique for GEM; however, because it is less sensitive and more prone to interferences, CVAAS is suitable for the higher air Hg concentrations that may occur in or near contaminated industrial sites. The automated, continuous gold-trap CVAFS method for GEM was first used in 1993 (Schroeder et al., 1995), and is by far the dominant choice for measuring Hg in ambient air (Valente et al., 2007). The automated method for continuously measuring GEM, GOM and PBM_{2.5} is described by Landis et al. (2002). Although there are numerous quality assurance measurements that can be made with GEM standards to quantify precision and accuracy, a major limitation is the lack of a standard reference source for calibration of GOM or PBM_{2.5} measurements at ambient air concentrations. Recent research has suggested for the first time that measured speciation ratios may be biased due to the potential for a variable fraction of collected GOM converting to GEM when ozone levels are elevated (Lyman et al., 2010). For measurements in the free troposphere where both ozone and GOM can be highly elevated, an alternative GOM collection method was used (Swartzendruber et al., 2006; Lyman and Jaffe, 2012). Additionally, the current measurement techniques for GOM and PBM_{2.5} do not identify the specific chemical forms of oxidised Hg, and this is a significant gap in the current understanding of atmospheric Hg chemistry as well as an area of ongoing research.

Mercury wet deposition is one of the most useful measurements of Hg that can be made to evaluate Hg input to sensitive ecosystems and monitor long-term trends. With proper trace-metal clean techniques, a high quality laboratory and relatively inexpensive equipment, wet-deposition of Hg can be measured routinely. Experts have demonstrated that four key components are required for accurate Hg wet deposition measurements: (i) a trace-clean sample train with an HCl preservative in the collection bottle, (ii) a temperature-controlled collector with an automated rain sensor, (iii) a rain gauge to verify the rainfall depth collected, and (iv) a CVAFS system to measure the Hg concentration (Vermette et al., 1995; Landis and Keeler, 1997; Mason et al., 2000; Lindberg et al., 2007). In addition, manual event-based Hg wet-deposition

sampling, which requires the presence of an operator to install and/or uncover the sample train for individual precipitation events, is also a possible technique for use in intensive studies (Dvonch et al., 1998; White et al., 2009). Both the U.S. EPA and the European Committee for Standardization (CEN) have developed standard methods for quantifying Hg in water samples (the U.S. EPA Method 1631 Revision E for determination of Hg in water samples, and the CEN EN ISO 17852 for determination of Hg wet deposition).

Tables 3.1 and 3.2 provide a summary of the existing networks for ambient air Hg and Hg wet deposition, respectively.

3.3.1 Europe

The European Monitoring and Evaluation Programme (EMEP) was one of the first international environmental

measurement networks established in Europe. Over the past 40 years, a number of atmospheric measurements, such as sulphur, nitrogen compounds, and ozone, have been made across 11 countries in Europe. In more recent years, EMEP has also expanded to include heavy metals, Hg, and some persistent organic pollutants (POPs). Heavy metals were officially included in the EMEP monitoring programme beginning in 1999. Several countries have also been measuring and reporting on heavy metals within the EMEP area in connection with different national and international programmes such as the Arctic Monitoring and Assessment Programme (AMAP), the Helsinki Commission (HELCOM, the governing body for the Convention on the Protection of the Marine Environment of the Baltic Sea Area), the OSPAR Commission (the governing body for the Convention for the Protection of the Marine Environment of the North-East

Table 3.1 Monitoring networks worldwide for measurements of mercury in ambient air.

Location	Programme	Region	Duration	Measurements	Source	Website
Europe	EMEP	Continental	From 1985	Automated and manual TGM ^a	Wängberg et al., 2007	www.emep.int
USA/Canada	NADP-AMNet	National	From 2009	Automated speciation	Prestbo et al., 2011	http://nadp.isws.illinois.edu/amn/
Canada	CAMNet	National	1996–2007	Automated TGM	Kellerhals et al., 2003; Steffen et al., 2005; Temme et al., 2007; Cole and Steffen, 2010; Cole et al., 2012	www.ec.gc.ca/rs-mn
	CAPMoN	National	From 2007	Automated TGM		
	CARA	National	From 2005	Automated speciation		
USA	UMAQL	Midwest	1999–2009	Manual TGM and PBM _{2.5} ; Automated speciation	Landis et al., 2002; Lynam and Keeler, 2005, 2006; Liu et al., 2007, 2010; Gratz et al., 2013a	
Polar Regions	AMAP	Arctic Circle	From 1991	Automated TGM		www.amap.no
Global	GMOS	Global	From 2011	Automated TGM/GEM and Automated speciation	Sprovieri et al., 2012	www.gmos.eu

^a TGM represent the total concentration of all forms of gaseous mercury compounds in ambient air. GEM: is the gaseous elemental mercury measured by removing the oxidized compounds by means of KCl coated denuders and particle-bound mercury by the sampling air stream. (Landis et al. 2002).

Table 3.2 Monitoring networks worldwide for measurements of mercury in wet deposition.

Location	Programme	Region	Duration	Measurements	Source	Website
Europe	EMEP	Continental	From 1987	Weekly to monthly; bulk and wet-only collection	Wängberg et al., 2007	www.emep.int
USA	NADP-MDN	National	From 1996	Weekly; wet-only collection	Butler et al., 2008; Prestbo and Gay, 2009; Risch et al., 2012	http://nadp.isws.illinois.edu/MDN/
	UMAQL	Midwest and Northeast	From 1992	Daily-event; wet-only collection	Burke et al., 1995; Landis et al., 2002; Keeler and Dvonch, 2005; Keeler et al., 2006; White et al., 2009; Gratz et al., 2009, 2013b; Gratz and Keeler, 2011	
	UMAQL	Florida	1995–2008–2010	Daily-event; wet-only collection	Dvonch et al., 1998, 1999, 2012	
Canada	CAMNet/CAPMoN	National	From 1996	Weekly; wet-only collection	Prestbo and Gay, 2009; Risch et al., 2012	www.ec.gc.ca/rs-mn
Global	GMOS	Global	From 2011	Weekly; wet-only and bulk collection	Sprovieri et al., 2012	www.gmos.eu

Atlantic), the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO), and the United Nations Framework Convention on Climate Change. EMEP continues to interact with and make use of research activities performed by the scientific community, particularly through the establishment of 'supersites' within other concurrent monitoring programmes.

The EMEP monitoring stations, however, are not uniformly distributed throughout Europe. Most sites are located in the northern, western and central parts of Europe, while only a few sites measure heavy metals in the southern and eastern parts of Europe. Mercury measurement data from EMEP are largely available only from north and northwest Europe. In 2003, 23 sites were measuring heavy metals in both air and precipitation, and 15 sites were measuring at least one form of Hg. The locations of the Hg measurement sites within the EMEP network are shown in Figure 3.1.

A particularly interesting and important Hg monitoring site within EMEP is the Mace Head site, which maintains the longest time series of atmospheric Hg measurements with high time resolution in the temperate marine background atmosphere. Mace Head is located on the west coast of Ireland (53°20'N; 9°54'W) and is exposed to the North Atlantic Ocean. TGM measurements using a Tekran Hg analyser (Model 2537A) (Ebinghaus et al., 2011) began in September 1995. Meteorological records indicate that about 50% of the air masses arriving at Mace Head are within the clean sector and have recently traversed the thousands of kilometres of uninterrupted fetch across the North Atlantic Ocean. There is no industrial activity that might influence measurements at the station within about 90 km of the site. TGM baseline measurements are considered representative of the unpolluted northern hemisphere and have been used to determine trends in TGM concentrations over the period 1995–2009 (Ebinghaus et al., 2011; see Section 3.4.1 for details).

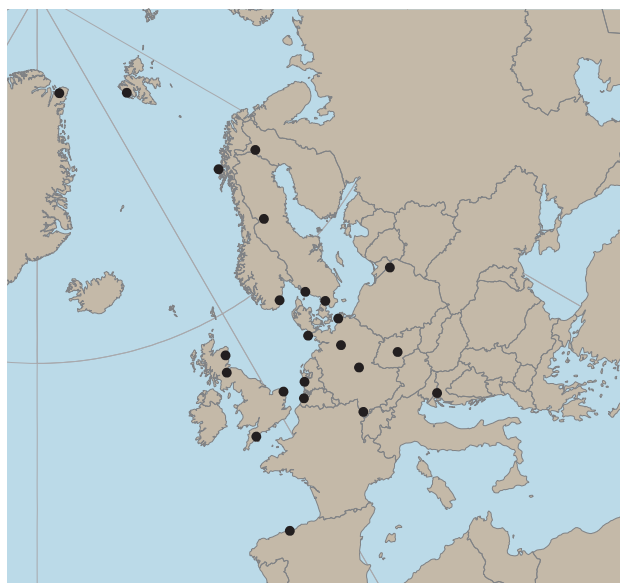


Figure 3.1 Mercury measurement sites within the EMEP network. Source: after Travníkov et al. (2012).

3.3.2 North America (USA and Canada)

3.3.2.1 Ambient mercury

In Canada, measurements of ambient air Hg and Hg wet deposition have been carried out through a series of monitoring networks led by Environment Canada, including the Canadian Air and Precipitation Monitoring Network (CAPMoN), the Canadian Atmospheric Monitoring Network (CAMNet), the Northern Contaminants Program (NCP), and the Canadian Clean Air Regulatory Agency (CARA). CAMNet began monitoring TGM at sites across Canada in 1996, and as of 2007 these measurements are conducted under the auspices of CAPMoN. There are currently four CAPMoN sites for continuous measurements of TGM. The NCP and Environment Canada have also been monitoring ambient air Hg at the Dr. Neil Trivett Global Atmospheric Watch Observatory at Alert, where measurements for GEM have been continuously measured since 1995 and speciated ambient Hg has been monitored since 2002. In 2005, the CARA Hg programme began monitoring speciated Hg at three sites in Canada, while NCP and Environment Canada added an additional site for Hg speciation. Currently, atmospheric Hg speciation is measured at four sites in total: Alert, St. Anicet, Kejimikujik, and the Experimental Lakes Area. Figure 3.2 shows the past and current atmospheric Hg monitoring at sites across Canada. A detailed analysis of all atmospheric Hg measurements in Canada is expected in the forthcoming Canadian Mercury Science Assessment, due out in 2013.

In the United States, a number of research-based individual monitoring sites and local/regional networks have existed over the years for measuring ambient air Hg. Recently, the Atmospheric Mercury Network (AMNet) was created within

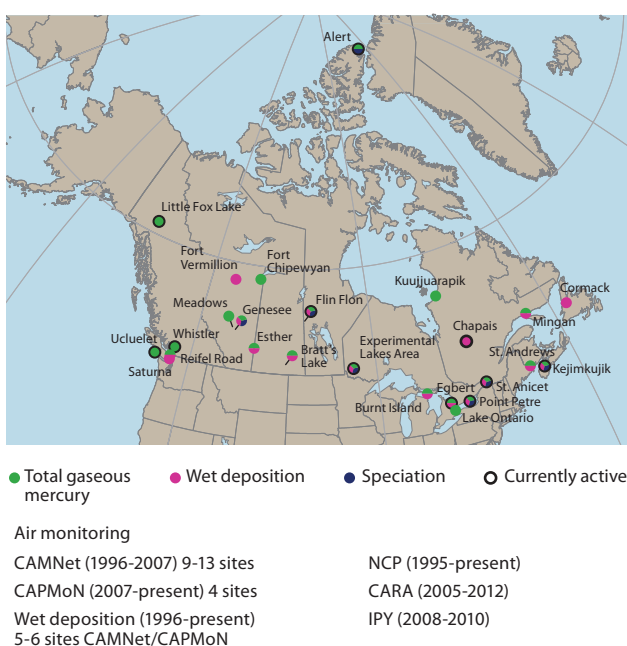


Figure 3.2 Locations of the past and current atmospheric mercury monitoring sites and networks across Canada. Source: Environment Canada.

the National Atmospheric Deposition Program (NADP) with the support of various U.S. government agencies and academic research communities, and in coordination with Canadian monitoring programmes. NADP and its partners launched AMNet by integrating several existing speciated Hg monitoring sites across the U.S. and Canada under a common framework. New monitoring sites were added to AMNet, as resources permitted. The network currently includes 21 sites where measurements of GEM, GOM and $\text{PBM}_{2.5}$ are made using the Tekran Hg speciation system (Sharac et al., 2011). AMNet was established for the purpose of measuring atmospheric Hg fractions, which contribute to dry and total Hg deposition. Sites measure concentrations of atmospheric Hg species from automated, continuous measuring systems, concentrations of total Hg in precipitation, and meteorological measurements, when available locally. Included in AMNet is a high-altitude site representative of background concentrations at Mauna Loa, Hawaii (discussed further in Section 3.5.1). Data from this site are available to the global community. In 2009, AMNet was formally recognised as a national network within the NADP and data products are available to anyone via their website (Figure 3.3). A significant contribution of AMNet has been the development of standard operating procedures (SOPs) for equipment operation and data management. The SOPs were developed with input and review from the majority of the atmospheric Hg monitoring experts from around the world. These SOPs have been a template for other network SOPs, such as the Global Mercury Observation System (GMOS) and also individual monitoring sites throughout the world, thus providing a common basis for data comparison.

While the Canadian CAMNet preceded AMNet in the development of SOPs for equipment operation and data management, it was imperative that both countries' ambient air Hg monitoring networks have equivalent quality assurance and quality control programmes and techniques for atmospheric Hg speciation data (Steffen et al., 2012). Efforts such as this will

help ensure that atmospheric Hg measurements collected on a network-scale are highly comparable and applicable to the modelling and policy communities.

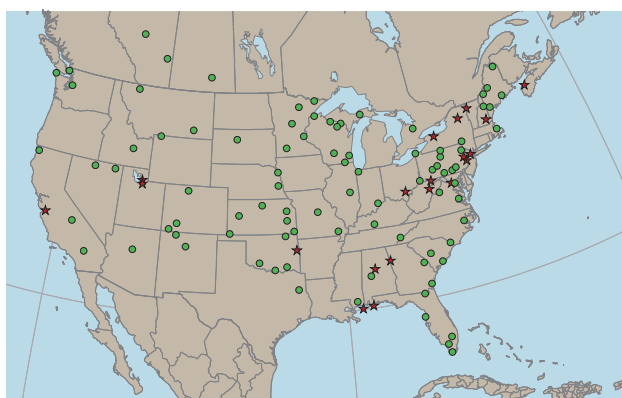
3.3.2.2 Mercury in precipitation

Long-term measurements of Hg wet deposition in the United States and Canada largely commenced in the mid-1990s following the Clean Air Act Amendments of 1990, which mandated monitoring of several hazardous air pollutants, including Hg. A number of monitoring sites were established (Figure 3.3), several of which are still operational today, producing nearly two decades of Hg wet-deposition records. In the Great Waters region, which includes the Great Lakes, Chesapeake Bay, and Lake Champlain basins, monitoring sites in Dexter (Michigan) and Underhill (Vermont) began in 1992 under the supervision of the University of Michigan Air Quality Laboratory (UMAQL). Additional sites were added in Pellston and Eagle Harbour (both in Michigan) in 1993, creating the foundations for the Michigan Mercury Monitoring Network that expanded over time to include other sites in Michigan, Ohio, and Illinois (Keeler and Dvonch, 2005; Keeler et al., 2006; Gratz et al., 2009; 2013b; White et al., 2009).

The NADP's Mercury Deposition Network (MDN) formed in 1996 and has grown to include more than 100 monitoring sites nationwide. The MDN programme (Figure 3.3) has also worked closely with the Canadian monitoring programmes, including CAMNet and CAPMoN, to develop consistent sample collection and analysis procedures. All precipitation samples from both the MDN and CAPMoN programmes are analysed at a common laboratory in the United States (Frontier Global Sciences) to ensure consistent analytical results. In more recent years, new sites have also been established in Mexico. As a result, the U.S. and Canadian monitoring networks have generated a long-term record of Hg wet deposition throughout North America over the past 20 years.

3.3.3 Asia

For nearly a decade, independent programmes and networks for monitoring atmospheric Hg species and deposition have been developed in Asia, such as those in Korea, Japan, China, and Taiwan. Most of the early measurements in this area were financially supported by the National Science Foundation in each of the Asian countries. A pilot project for monitoring atmospheric Hg started in 2007 at the Cape Hedo site on Okinawa Island of Japan (Suzuki et al., 2009), where continuous measurements began with TGM only and now include continuous measurements of GOM and $\text{PBM}_{2.5}$ (Japan Ministry of the Environment, 2012). Since the establishment of the GMOS project, many of these sites have been incorporated into GMOS (Sprovieri et al., 2012). At present, there are nine ground-based monitoring sites in Asia involved in the GMOS monitoring network. Of the nine GMOS sites in Asia, four ground-based sites including Mt. Waliguan baseline observatory, Mt. Changbai station, Mt. Aishao station and Mt. Lulin Atmospheric Background station are



Mercury networks (January 2012)

★ AMNet ● MDN

Figure 3.3 NADP Mercury Deposition Network Sites (MDN, <http://nadp.isws.illinois.edu/MDN/>) and NADP Air Mercury Network Sites (AMNet, <http://nadp.isws.illinois.edu/amn/>). Source: National Atmospheric Deposition Program and Prestbo et al. (2011).

located in China, and respectively represent the background monitoring of atmospheric Hg species and wet deposition in the northwest, northeast, and southwest of China and Taiwan. Two sites in Japan, located in Cape Hedo (Okinawa Island) and Minamata (Kyushu Island), were also selected as GMOS ground-based sites. The GMOS monitoring sites in Korea and India are located in Kanghwa Island (northwestern Korea) and Kodaikanal (southern India), respectively. In addition, the highest-altitude site in the GMOS monitoring network, EvK2CNR, is located in the northeastern area of Nepal. These measurement sites are an important addition to the GMOS network and will improve understanding of atmospheric Hg species in this area of the world.

3.3.4 Polar regions (Arctic and Antarctica)

The Arctic Monitoring and Assessment Programme (AMAP) established in 1991, is a coordinated air monitoring programme covering the circum-Arctic areas of North America and Eurasia. The AMAP programme has an active ambient air Hg monitoring component with sites in Canada, USA, Russia, Norway and Greenland (Denmark). The Global Atmospheric Watch (GAW) site at Alert operated by Environment Canada has the longest, continuous record of GEM (17 years) and Hg speciation (10 years) in the Arctic. Continuous monitoring for long periods has also occurred at: (1) Amderma (Russia), (2) GAW Ny Alesund 'Zeppelin' site (Svalbard, Norway) and (3) AMAP 'Station Nord' (Greenland-Denmark). Shorter term Arctic ambient air Hg monitoring and research has occurred at several other sites. There were no monitoring networks for atmospheric Hg species established in Antarctica before the establishment

of GMOS. However, several important short-term Antarctic ambient air measurements were carried out during episodic field campaigns. The Antarctic regions have not been extensively monitored yet, and so there is little information available on spatial and temporal trends in atmospheric Hg there. Currently, the GMOS network is supporting or associated with key Arctic sites such as Zeppelin (Svalbard, Norway), Station Nord (Greenland-Denmark), and Alert (Ellesmere Island, Canada). In Antarctica, the GMOS network includes the GAW French-Italian monitoring Station 'DOME-C' on the Antarctic Plateau and the GAW coastal French Research Station, 'Dumont d'Urville'.

3.3.5 GMOS

The Global Mercury Observation System (GMOS) project (www.gmos.eu) commenced in November 2010 with the goal of developing a coordinated global observation system for Hg, including a large network of ground-based monitoring stations in order to improve the global-scale coverage of atmospheric Hg measurements. The GMOS ground-based stations (see Figure 3.4) are primarily remote background monitoring sites at both high altitude and sea level locations. New sites are being developed in regions of the world where few observational data are available on atmospheric Hg. The measurements from these sites will be used to assess levels of atmospheric Hg and Hg deposition at individual monitoring sites, as well as to validate regional and global scale atmospheric Hg models. This information will improve understanding of global atmospheric Hg transport and deposition, and it will importantly contribute to future international policy development and implementation.

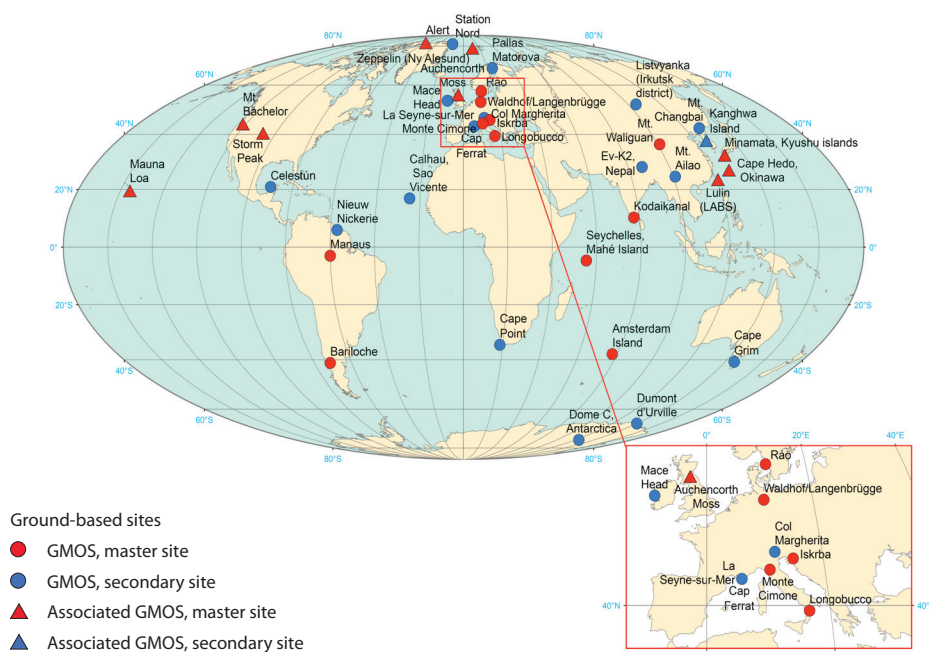


Figure 3.4 Ground-based monitoring sites participating in the GMOS programme (www.gmos.eu). GMOS Master sites are those where GEM, GOM, and PBM_{2.5} are continuously measured and Hg in rainfall measured where appropriate. Secondary GMOS sites are those where only TGM and Hg in precipitation are continuously measured. Associated GMOS sites are those that are managed by external GMOS partners who have agreed to share their measurement data with the GMOS programme and measurement database.

To date, there are 38 monitoring sites participating in the GMOS network. These include existing sites that are already collecting atmospheric Hg measurements (ambient air and/or precipitation), in particular several global monitoring sites such as Mace Head (Ireland) and Cape Point (South Africa) which have been monitoring concentrations of atmospheric Hg for many years and can offer an important historical measurement record to the project (Sprovieri et al., 2012). The GMOS network also includes new background stations (with an emphasis on the southern hemisphere regions where networks did not previously exist) which are initiating Hg measurements for the first time, and externally partnering sites who are contributing their measurement data to the GMOS database.

3.4 Atmospheric mercury measurements and trends worldwide

3.4.1 Ambient atmospheric mercury measurements and trends

3.4.1.1 Europe

Extensive measurements and data analysis have been performed at the Mace Head (Galway, Ireland) monitoring site for nearly two decades. Overall, a decreasing trend in TGM concentrations was observed at Mace Head from 1996 to 2011, and these findings have been an important new contribution to the scientific literature (Ebinghaus et al., 2011). To determine trends in TGM, it was important to select air masses that were representative of the unpolluted northern hemispheric marine boundary layer. At Mace Head, an atmospheric dispersion modelling method (Ryall et al., 1998) was employed to separate baseline air measurements. The modelling techniques are described in more detail by Ryall and Maryon (1998) and Ryall et al. (1998), and further refinements to the model using a back-attribution technique are described by Manning et al. (2003). As an example, Figure 3.5 shows the composite of all air mass history maps assigned to the baseline category for 1998.

Air masses, assigned to the baseline category on an hourly basis, were extracted from the complete dataset to form a baseline meteorological dataset (Ebinghaus et al., 2011). The hourly average TGM observations were then extracted from this baseline dataset to form a baseline TGM dataset for the baseline hours only. Over the 16-year period of this study, 28.6% of TGM observations were assigned to baseline air masses. Calendar month averages for TGM were then calculated for baseline air masses from the hourly values. No lower limit value was set on the number of hourly observations needed to characterise a valid monthly average. This averaged monthly baseline shows evidence of a seasonal cycle that

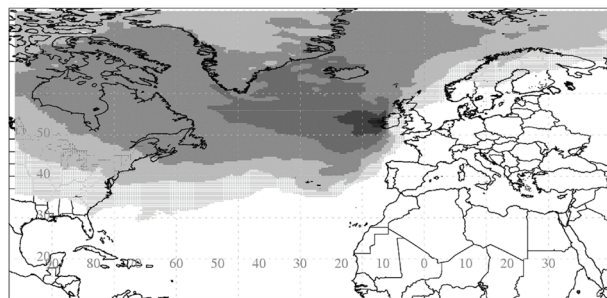


Figure 3.5 A composite of the back-attribution plots for Mace Head, Ireland for all air masses assigned to the baseline category during 1998, with the pixel shading showing the relative contribution to the air concentration at Mace Head, Ireland from the emissions of an inert tracer at that location. Source: Ebinghaus et al. (2011).

is consistent with those observed at Mace Head for a wide variety of trace gases. It is suggested that meteorological variability is the most important factor in the establishment of the observed seasonal cycle of TGM concentrations. The presence of trends was investigated with the application of the Mann-Kendall test and Sen's slope estimate. Annual baseline TGM means decreased from 1.82 ng/m³ in 1996 to 1.40 ng/m³ in 2011. They showed a statistically significant negative (downward) trend of -0.027 ± 0.01 ng/m³/y (at the 99.9% level of significance), which is 1.4–1.8% per year or 26% in the 16 years of investigation (Ebinghaus et al., 2011).

In a recent publication by Slemr et al. (2011), these observations at Mace Head were compared with similar long-term measurements at the Cape Point station in South Africa, as well as with atmospheric Hg measurements from oceanographic cruise campaigns. Cape Point has been an important monitoring site for atmospheric Hg for many years. It is a WMO-GAW station approximately 60 km south of Cape Town (Slemr et al., 2011). From 1995 to 2004, TGM was measured using manual techniques (Slemr et al., 2008), and from March 2007 to the present TGM has been measured using a Tekran automated Hg vapour analyser (Slemr et al., 2011). From 1999 to 2010, GEM concentrations decreased at Cape Point by -0.034 ± 0.005 ng/m³/y. When cruise measurements from the southern hemisphere were included in this calculation, the observed declining trend was -0.035 ± 0.005 ng/m³/y (Slemr et al., 2011). When a similar analysis was applied to the Mace Head annual dataset, a declining trend of -0.025 ± 0.005 ng/m³/y was observed from 1996 to 2009, which is similar to the value reported above from Ebinghaus et al. (2011) that was obtained using baseline monthly averages (Slemr et al., 2011). These analyses provide a unique comparison of long-term trends in atmospheric Hg in the northern and southern hemispheres, and suggest that ambient TGM concentrations have declined significantly at both examined sites.

With regard to speciated atmospheric Hg measurements in Europe, since January 2009, atmospheric concentrations of GEM, GOM and PBM_{2,5} have been measured continuously at the EMEP monitoring station 'Waldhof', Germany (52°48'N, 10°45'E), a rural background measurement site of the German

Federal Environment Agency (Figure 3.6). Waldhof was chosen to be one of four European GMOS master sites for continuously measuring speciated atmospheric Hg concentrations. The measurements are performed in quasi-continuous mode, using an automatic Hg analyser (Tekran model 2537A) together with a Hg speciation unit (Tekran model 1130 and Tekran model 1135). GEM is measured every five minutes, while GOM and PBM_{2.5} are sampled at three-hour intervals.

Figure 3.6 illustrates the daily average concentrations for GEM (black), PBM_{2.5} (red) and GOM (blue) from January 2009 to December 2011. During this three-year period, the daily median GEM concentrations varied between 1.4 and 2.0 ng/m³ (10% and 90% percentiles). The minimum and maximum daily average concentrations were 1.1 and 3.1 ng/m³, respectively. The three-year median concentration was 1.63 ng/m³, similar to the northern hemispheric background concentration of 1.7 ng/m³ (Ebinghaus et al., 2011). The median TPM concentration (6.74 pg/m³) was about five times higher than the median GOM concentration (1.27 pg/m³). PBM_{2.5} and GOM showed much larger variability in daily average concentration than GEM. Based on yearly median concentrations, between 2009 and 2011 there was no trend apparent in GEM and PBM_{2.5} concentrations (Table 3.3). In contrast, the yearly median GOM concentration increased by 76% from 2009 to 2010 and by 34% from 2010 to 2011. However, given the statistical limitations of the data set (three years of measurements at one site), the indicated trend will need to be verified with continuous measurements in the coming years.

A first seasonality analysis at Waldhof was carried out using monthly average concentrations. The most pronounced seasonal variation was observed in PBM_{2.5} concentrations (Figure 3.7). During winter, the concentrations as well as the variability appear

Table 3.3 Yearly average concentrations (medians) for GEM, PBM_{2.5} and GOM, measured at the German EMEP station and measurement site of the German Federal Environmental Agency, 'Waldhof'. Source: Weigelt et al. (2012).

Year	GEM, ng/m ³	PBM _{2.5} , pg/m ³	GOM, pg/m ³
2009	1.66	7.20	0.73
2010	1.61	6.68	1.29
2011	1.61	6.42	1.72

much higher than in summer. The PM_{2.5} mass concentration is given in Figure 3.7 in blue, averaged for the same time periods as PBM_{2.5}. It is clear that PBM_{2.5} concentrations show a similar seasonality as the PM_{2.5} mass concentrations. Higher PM_{2.5} mass concentrations in winter may reflect increased emissions in winter (e.g., from domestic heating) as well as meteorological effects (e.g., reduced height of the planetary boundary layer; Seinfeld and Pandis, 1998). Neither GEM nor PBM_{2.5} show a significant diurnal cycle (not shown), whereas, a daily cycle is highly apparent for GOM (Figure 3.8). Currently it is assumed that the observed cycle is caused by local photochemical oxidation and *in situ* production of GOM.

3.4.1.2 North America

In North America, the development of national monitoring networks, regional monitoring programmes and intensive measurement campaigns has lead to the collection of various important datasets on both TGM and speciated atmospheric Hg. In Canada, the CAMNet programme's continuous monitoring of TGM has made it possible to examine temporal and spatial variability in TGM concentrations (Blanchard et al., 2002; Kellerhals et al., 2003; Temme et al., 2007). In general,

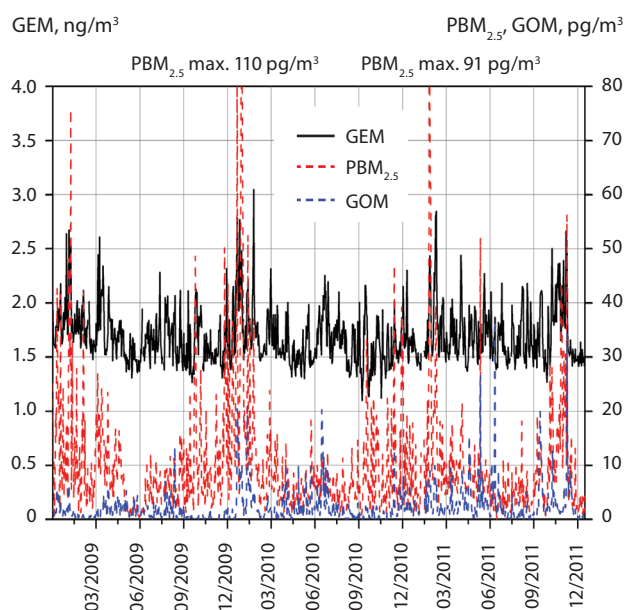


Figure 3.6 Daily averages for GEM, PBM_{2.5} and GOM from January 2009 to December 2011 at the German EMEP station and measurement site 'Waldhof'. Source: Weigelt et al. (2012).

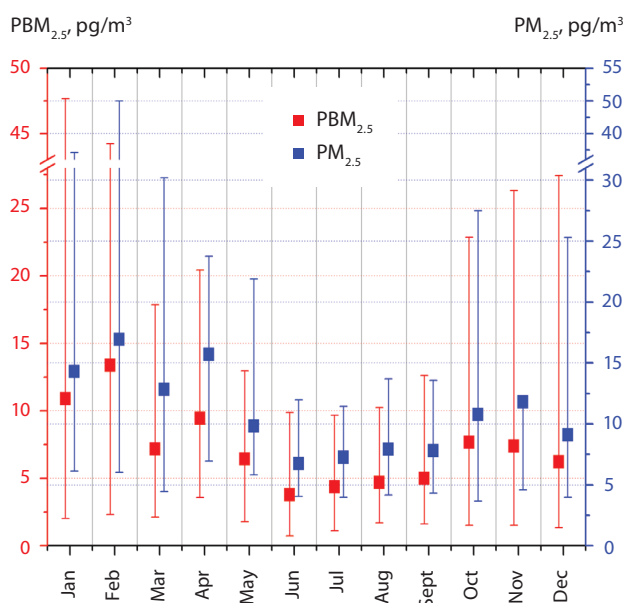


Figure 3.7 Monthly median concentration for particle bound mercury (PBM_{2.5}) and particle mass (PM_{2.5}) at the Waldhof air monitoring site, Germany (2009–2011). Source: Weigelt et al. (2012).

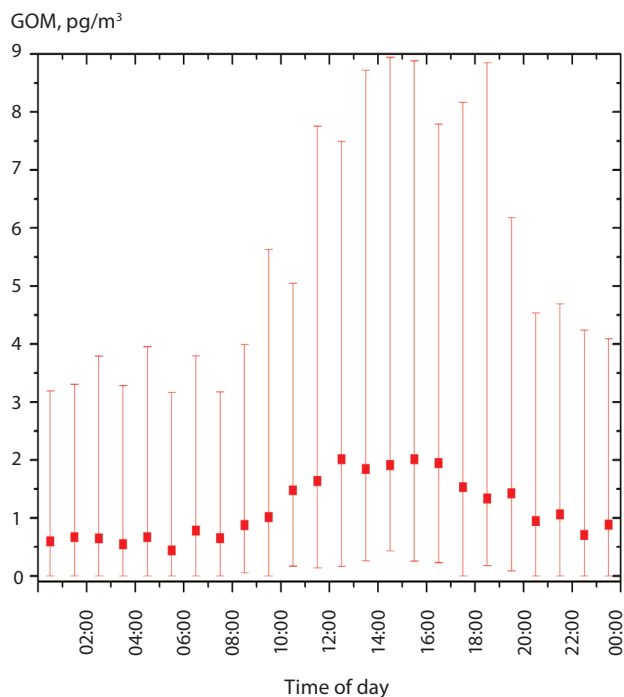


Figure 3.8 Hourly median concentration for GOM at the Waldhof air monitoring site, Germany (2009–2011). Source: Weigelt et al. (2012).

mid-latitude sites showed slightly higher TGM concentrations in late winter, and lower concentrations in summer, while diurnally the maximum concentration typically occurred near solar noon and the minimum concentration before sunrise (Kellerhals et al., 2003). It was also clear that, although the monitoring sites are in primarily rural locations, those sites that are closer to anthropogenic source regions (classified as ‘rural-affected’) displayed significantly higher TGM concentrations (1.70 ng/m³ on average) than rural-remote sites (1.54 ng/m³ on average) (Kellerhals et al., 2003).

Temme et al. (2007) identified a statistically significant decreasing trend in TGM concentrations at certain rural CAMNet sites from 1995 to 2005. Declines in concentration by site varied from 2.2% to 17.4%, and these findings appeared consistent with reported reductions in concentrations of Hg in precipitation at North American MDN sites (Temme et al., 2007). In addition to CAMNet, monitoring of speciated atmospheric Hg has also been carried out at selected sites in Canada (see Table 3.4).

A more recent study by Cole et al. (2012) examined 10-year trends in atmospheric TGM in the Canadian High Arctic, sub-Arctic, and mid-latitude regions. Specifically at the sub-

Table 3.4 Summary of selected studies of atmospheric TGM and speciated mercury concentrations in North America. Presented values are either reported as the mean (\pm SD) or a range of values depending on the specific study design and convention for data reporting in the literature.

Location	Region	Period	Measurements	TGM, ng/m³	GEM, ng/m³	PBM _{2,3} , pg/m³	GOM, pg/m³	Source
Canada	National (CAMNet)	1997–1999; 1995–2005	Automated TGM	1.60 \pm 0.15 1.58 \pm 0.17				Kellerhals et al., 2003; Temme et al., 2007
	Bay St. François	2002	Automated speciated Hg	1.40 \pm 0.17	1.38 \pm 0.18	6.44 \pm 3.63	3.63 \pm 4.07	Poissant et al., 2004
	St. Anicet, Quebec	2003	Automated speciated Hg		1.65 \pm 0.42	26 \pm 54	3 \pm 11	Poissant et al., 2005
USA	Southern Lake Michigan (LMMBS and AEOLOS)	1994–1995	Manual TGM; manual PBM _{2,3} ; automated TGM	(mean values) 2.1–3.6 1.7–4.1		(mean values) 12–70 6–133		Landis et al., 2002
	SE Michigan (Dexter, Detroit)	1999–2002	Automated speciated Hg		1.09–4.39 1.09–15.74	(Detroit only) 5.70–60.1	0.19–38.7 0.62–155	Lynam and Keeler, 2005
	SE Michigan (Detroit)	2003	Automated speciated Hg		2.2 \pm 1.3	20.8 \pm 30.0	17.7 \pm 28.9	Liu et al., 2007
	SE Michigan (Dexter, Detroit)	2004	Automated speciated Hg		1.59 \pm 0.59 2.47 \pm 1.43	6.10 \pm 5.51 18.1 \pm 61.0	3.80 \pm 6.62 15.5 \pm 54.9	Liu et al., 2010
	New York (Potsdam, Stockton, Sterling)	2001–2002	Manual TGM; manual GOM	1.84 \pm 1.24 1.83 \pm 1.32 3.02 \pm 2.14			4.2 \pm 0.64 5.7 \pm 9.2 6.0 \pm 10.8	Han et al., 2004
	New York (Adirondacks)	2006–2007	Automated speciated Hg		1.4 \pm 0.4	3.2 \pm 3.7	1.8 \pm 2.2	Choi et al., 2008
	20 AMNet Sites	2008–2009	Automated speciated Hg		(annual mean) 1.2–2.1	(annual mean) 2.9–17.1	(annual mean) 1.1–22.6	Zhang et al., 2012a

Arctic (Kuujuarapik, Nunavik, Quebec, Canada) and mid-latitude sites (St. Anicet, Quebec, Kejimikujik, Nova Scotia and Egbert, Ontario, Canada) (Cole et al., 2012), analysis of TGM concentrations showed a decreasing trend from 1995 to 2007. The decline at the sub-Arctic Kuujuarapik site was -2.1% per year, whereas at the mid-latitude sites the declines were -1.9%, -1.6%, and -2.2% per year for St. Anicet, Kejimikujik, and Egbert, respectively (Cole et al., 2012). These trends are in close agreement with that observed since 1996 at Mace Head, Ireland ($-1.8 \pm 0.2\%$ per year) (Ebinghaus et al., 2011; see also Section 3.4.1.1).

In the United States, a number of ambient air Hg measurement campaigns have been carried out in the Midwest and the Great Lakes regions, in part because of the high density of atmospheric Hg emission sources in that area. A brief summary of the results from selected studies of ambient air Hg (both TGM and speciated Hg) in North America are presented in the Table 3.4, and references for the associated manuscripts are provided for further details. Earlier studies, such as the Lake Michigan Urban Air Toxics Study (LMUATS) (Holsen et al., 1992; Keeler, 1994), the Lake Michigan Mass Balance Study (LMMBS) (Landis et al., 2002; McCarty et al., 2004) and the Atmospheric Exchange Over Lakes and Oceans Study (AEOLOS) (Landis et al., 2002), demonstrated the important local and regional scale impacts of the Chicago/Gary urban area on TGM concentrations and levels of Hg deposition to ecosystems in the Lake Michigan Basin. Results from the LMMBS suggested that atmospheric deposition was responsible for approximately 84% of total annual Hg inputs to Lake Michigan, and that the Chicago/Gary urban area contributed approximately 20% of the annual atmospheric Hg deposition to the lake (Landis and Keeler, 2002). A more recent study using speciated ambient Hg measurements of GEM, GOM, and $\text{PBM}_{2.5}$ in Chicago (Illinois) and the downwind receptor site of Holland (Michigan) demonstrated that transport from Chicago/Gary across Lake Michigan may result in GOM concentrations at downwind receptors that are enhanced five-fold relative to transport from other directions (Gratz et al., 2013a). In specific cases of this type of transport, 50% of the elevated GOM concentrations were attributed to direct transport of primary GOM source emissions, with the remainder associated with GEM oxidation during transport (Gratz et al., 2013a). Speciated Hg measurements in the Detroit (Michigan) urban area and in the remote upwind site of Dexter (Michigan) have demonstrated the significant differences in speciated Hg between the two locations as well as the substantial local impacts that industrial emission sources can have on the levels of speciated Hg, in particular GOM, within an urban/industrial area (Lynam and Keeler, 2005, 2006; Liu et al., 2007, 2010). A study in New York state also demonstrated the elevated levels of GOM at a monitoring site near major industrial sources (Sterling), while at more remote sites (Potsdam and Stockton) GOM concentrations were noticeably lower (Han et al., 2004).

Owing to the time periods of many of these studies (of the order of a few months to one year, and in different geographic locations) it can be difficult to determine overall long-term trends in speciated Hg concentrations in the United States. However, a recent study by Mao and Talbot (2012) explored temporal patterns and trends in speciated atmospheric Hg at marine (Appledore Island), coastal (Thompson Farm), and inland (Pac Monadnock) sites in New Hampshire, USA. Analyses demonstrated decreasing trends in GEM at the coastal and inland sites of 3.3 ppqv/y over 7.5 years (2003–2010) and 6.3 ppqv/y over 5.5 years (2005–2010), respectively (Mao and Talbot, 2012). These observed declines are comparable to those reported at Mace Head, Ireland ($-0.028 \pm 0.01 \text{ ng/m}^3/\text{y}$, or $-3.1 \pm 1.1 \text{ ppqv/y}$) and at Cape Point, South Africa ($-0.034 \pm 0.005 \text{ ng/m}^3/\text{y}$, or $-3.8 \pm 0.6 \text{ ppqv/y}$). The study by Mao and Talbot (2012) represents the first attempt to explore long-term trends in atmospheric GEM at mid-latitude sites in the United States.

The Thompson Farm site is an example of one of many sites in the United States and Canada that have been in operation for several years and are now part of the NADP AMNet monitoring programme. Figure 3.9 shows the annual concentrations of

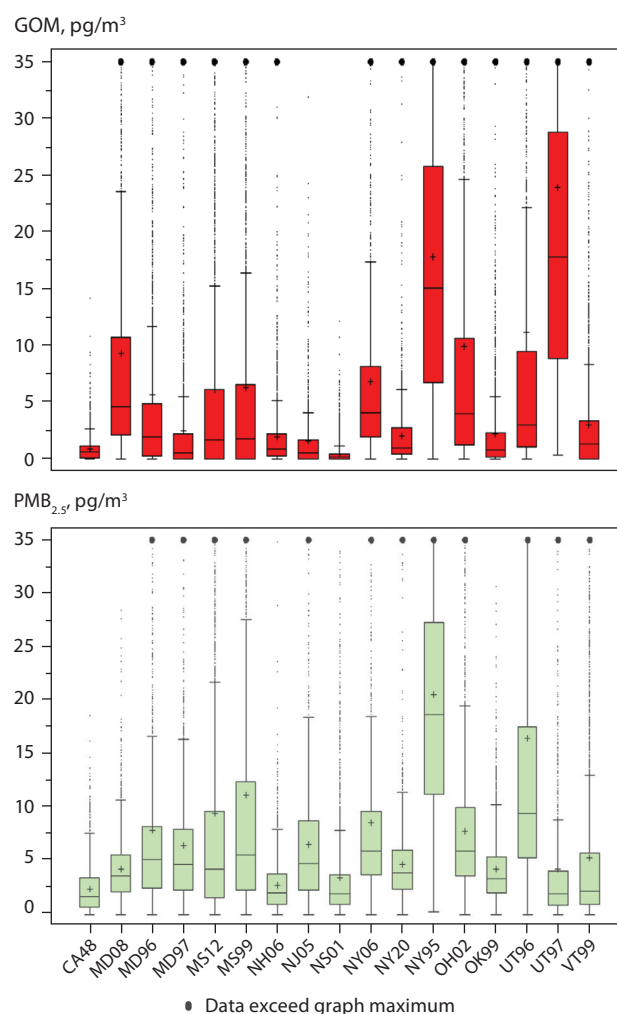


Figure 3.9 Annual GOM and $\text{PBM}_{2.5}$ observations for AMNet sites in 2010. The box whisker plots for each field site show the median (horizontal line), 70th percentile (box), 95th percentile (whisker). In general, urban and regionally impacted sites had the highest mercury speciation values, while remote coastal sites had the lowest. Source: Prestbo et al. (2011).

GOM and $\text{PBM}_{2.5}$ at AMNet sites for 2010 (Prestbo et al., 2011), demonstrating interesting variability in ambient concentrations between urban and remote sites. Zhang et al. (2012a) reported on concentrations of atmospheric Hg species across 20 AMNet sites from 2008–2009 (Table 3.4) and used the measurement dataset to estimate speciated and total Hg dry deposition. Across these sites, the annual GEM concentrations ranged from 1.2 to 2.1 ng/m^3 and the highest concentrations were observed at urban and suburban locations, whereas for GOM and $\text{PBM}_{2.5}$ the annual concentrations were more variable among the sites. While the lowest concentrations of GOM and $\text{PBM}_{2.5}$ were observed at the same rural sites, the highest concentrations of GOM and $\text{PBM}_{2.5}$ were not observed at the same sites, and the observed geographical and seasonal patterns in atmospheric Hg species were attributed to several factors, including source emissions, atmospheric transport, chemical cycling, and deposition processes (Zhang et al., 2012a). As the AMNet programme continues to grow and develop, many interesting results pertaining to spatial and temporal variability in speciated ambient air Hg concentrations should become available, further informing the scientific community about the levels and long-term trends of ambient air Hg in North America.

3.4.1.3 Asia

Speciated atmospheric Hg measurements in urban and remote areas in Asia are shown in Table 3.5. Feng et al. (2004) carried out one year of continuous TGM measurements in Guiyang, south-western China. A clear seasonal pattern of TGM concentrations was observed in Guiyang, with elevated levels in cold seasons. Results indicate that TGM levels in Guiyang are much higher than in other cities around the world. Coal combustion for domestic heating and industrial activity is believed to be the major source of these elevated levels of TGM. Continuous measurements of speciated atmospheric Hg (GEM, $\text{PBM}_{2.5}$, GOM) in Guiyang were also conducted in 2009. The mean GEM, $\text{PBM}_{2.5}$ and GOM levels observed are all higher than those typically observed in urban areas of North America and Europe (Fu et al., 2011). Several short-term studies (several weeks to several months) of TGM have been undertaken in Shanghai, Ningbo (eastern China) and Chongqing (south-western China). The mean TGM concentrations recorded in Shanghai and Ningbo are much lower than those observed in Guiyang and Chongqing (mean: $6.74 \pm 0.37 \text{ ng}/\text{m}^3$, Yang et al., 2009), which is likely to be due to the exchange of clean air masses from marine areas.

In Seoul, South Korea, atmospheric Hg levels have shown a clear decreasing trend in the last decade. The concentrations in Seoul are much lower than those reported from Guiyang and Chongqing in southwest China (Fu et al., 2011). However, the mean TGM concentration in Seoul is comparable to those obtained in Shanghai and Ningbo, which are located in coastal areas of eastern China (Friedli et al., 2011; Nguyen et al., 2011).

Observations of TGM in remote areas of Asia are in the range 1.7–4.6 ng/m^3 , which are relatively high compared to background concentrations in the northern hemisphere (1.5–1.7 ng/m^3 , Lindberg et al., 2007). At the Cape Hedo Observatory in Japan, the mean GEM concentration is slightly higher than the northern hemisphere background values obtained during the observation campaign in 2004, whereas GOM and $\text{PBM}_{2.5}$ were similar to observations in North America and Europe (Valente et al., 2007). This may suggest that the export of atmospheric Hg from Asia is mainly in the form of GEM, and outflow of GOM and $\text{PBM}_{2.5}$ in the Eastern Asian boundary layer is very limited. Cape Hedo is occasionally impacted by plumes that originate from mainland China and central Japan, and this contributes to the relatively high mean TGM. In China, TGM concentrations measured in the Mt. Gongga area were significantly higher than those observed at other remote sites (Table 3.5). The elevated TGM and $\text{PBM}_{2.5}$ levels at Mt. Gongga were attributed to emissions of Hg from local domestic coal combustion and regional non-ferrous metal smelting activities (Fu et al., 2008a,b). There are no pollution control devices used during domestic burning, and the Hg emission factors for domestic coal and bio-fuel burning are likely to be significantly higher than for power plants and industrial boilers (Streets et al., 2005; Tang et al., 2007). Fu et al. (2010a) conducted a full year study of TGM at a remote site (Mt. Leigong, 2178 m a.s.l.) in Guizhou province, south-western China. This study showed a mean concentration higher than the northern hemisphere background value suggesting that this site is a frequent receptor for long-range transport of atmospheric Hg pollution from central China (e.g., Henan, Hubei, and Hunan provinces).

A one-year monitoring study of atmospheric speciated Hg was performed at Mt. Waliguan Observatory (Fu et al., 2012b). This site is one of 24 baseline WMO-GAW sites. This high altitude station (3816 m a.s.l.) on the edge of the north-eastern Qinghai-Tibetan Plateau is relatively isolated from industrial point sources and populated regions. Annual mean TGM, $\text{PBM}_{2.5}$ and GOM concentrations at this site were slightly higher than those reported from remote areas of North America and Europe (Valente et al., 2007). The speciated Hg concentrations showed a pronounced dependence on wind direction, with most of the high concentrations observed under north-easterly and easterly flow patterns. Urban areas such as Xining and Lanzhou were the most important regional source areas. In addition, long-range transport of Hg-enriched air masses from eastern Gansu, western Shanxi, western Ningxia as well as northern India also partially influenced the observations (Fu et al., 2012b).

Measurements of atmospheric TGM concentrations were also conducted in rural-affected sites in coastal areas of the Yellow Sea. The Yellow Sea is bordered by eastern China and the Korean Peninsula, which are important Hg source regions in East Asia. Most of the high-TGM events were observed close to the mainland of East China, indicating the effect of outflow of air masses from the mainland.

Table 3.5 Summary of speciated atmospheric mercury concentrations observed in Asia.

Location	Classification	Period	Method	TGM, ng/m ³	PBM, pg/m ³	GOM, pg/m ³	Source
Guiyang, China	Urban	Nov 2001 – Nov 2002	Tekran 2537	8.40 ± 4.87			Feng et al., 2004
		Aug–Dec 2009	Tekran 2537-1130-1135	9.7 ± 10.2	368 ± 676	35.7 ± 43.9	Fu et al., 2011
Chongqing, China	Urban	Aug 2006 – Sep 2007	Lumex RA-915+	6.74 ± 0.37			Yang et al., 2009
Shanghai, China	Urban	Aug–Sep 2009	Tekran 2537	2.7 ± 1.7			Friedli et al., 2011
Ningbo, China	Urban	Oct 2007 and Jan 2008	Lumex RA-915+	3.79 ± 1.29			Nguyen et al., 2011
Seoul, South Korea	Urban	Feb 2005 – Feb 2006	TGM: Tekran 2537 PBM and GOM: Manual	3.22 ± 2.10	23.9 ± 19	27.2 ± 19.3	Kim et al., 2009
Tokai-mura, Japan	Urban	Oct 2005 – Aug 2006	Mercury/AM-3, Nihon	3.78 ± 1.62			Osawa et al., 2007
Cape Hedo, Japan	Remote	Oct 2007 to present	Tekran 2537	1.9 ± 0.5	2.2 ± 4.2	1.3 ± 3.1	Japan Ministry of Environment, 2012
Jeju Island, Korea	Remote	May 2006 – May 2007	Manual method	3.85 ± 1.68			Nguyen et al., 2010
An-Ayun Island, Korea	Remote	Dec 2004 – Apr 2006	Mercury/Am-2, Nippon	4.61 ± 2.21			Nguyen et al., 2007
Cape Hedo, Japan	Remote	March – May 2004	Tekran 2537-1130-1135	2.04 ± 0.38	4.5 ± 5.4	3.0 ± 2.5	Chand et al., 2008
Mt. Gongga, China	Rural-affected	May 2005 – July 2007	TGM: Tekran 2537 PBM and GOM: Manual	3.98 ± 1.62	30.7 ± 32.1	6.2 ± 3.9	Fu et al., 2008a,b
Mt. Changbai, China	Rural-affected	Aug 2005 – Jul 2006	Tekran 2537-1130-1135	3.58 ± 1.78	77 ± 136	65 ± 84	Wan et al., 2009a,b
Chengshantou, China	Rural-affected	Jul 2007 – May 2009	Lumex RA-915+	2.31 ± 0.74			Ci et al., 2011
Mt. Changbai, China	Remote	Oct 2008 – Oct 2010	Tekran 2537	1.60 ± 0.51			Fu et al., 2012a
Mt. Leigong, China	Remote	May 2008 – May 2009	Tekran 2537	2.80 ± 1.51			Fu et al., 2010a
Mt. Waliguan, China	Remote	Sep 2007 – Aug 2008	TGM: Tekran 2537 PBM and GOM: Manual	1.98 ± 0.98	19.4 ± 18.1	7.4 ± 4.8	Fu et al., 2012b
Shangri-La, China	Remote	Nov 2009 – Nov 2010	TGM: Tekran 2537 PBM and GOM: Manual	2.59 ± 1.33	43.5 ± 41.6	8.2 ± 9.4	Zhang et al., 2012a
Lulin, Taiwan, China	Remote	Apr 2006 – Dec 2007	Tekran 2537-1130-1135	1.73 ± 0.61	2.3 ± 3.9	12.1 ± 20.0	Sheu et al., 2010

Speciated atmospheric Hg measurements have been conducted in Taiwan, China. The Lulin Atmospheric Background Observatory is on the summit of Mt. Front Lulin in central Taiwan (Sheu et al., 2010). Variation in GEM concentrations at Lulin station was partially determined by the Asian Monsoon. During autumn, winter, and spring, increased outflows of atmospheric Hg from mainland China arrived at Lulin station.

3.4.1.4 Polar regions (Arctic and Antarctica)

The discovery of AMDEs at Alert (Canadian Arctic) in 1995 (Steffen et al., 2008) revolutionised the understanding of Hg cycling in polar regions while stimulating research into atmospheric Hg processes and their impact on this fragile ecosystem. The first annual time series of atmospheric Hg concentrations in the Arctic was obtained at Alert in 1995 (Schroeder et al., 1998). GEM depletion from the Arctic boundary layer has been observed at several locations throughout the Arctic (Sprovieri et al., 2005; Steffen et al., 2008) highlighting that AMDEs occur from the snow surface (Berg et al., 2003; Sprovieri et al., 2005; Sommar et al., 2007; Steffen et al., 2008) up to a maximum altitude of 1 km (Banic et al., 2003). Simultaneous depletion of boundary layer Hg and O₃ have been observed to occur annually at numerous maritime circumpolar sites (Schroeder et al.,

1998; Ebinghaus et al., 2002; Lindberg et al., 2002; Skov et al., 2004). The reason for the rapid decrease in both Hg and O₃ concentrations is believed to be reaction with halogen, and in particular Br-containing compounds. Figure 3.10 shows the production of atmospheric Br closely connected to refreezing leads where bromide is pushed out to the surfaces during the refreeze of seawater under sunlight conditions and the possible fate of Hg after its chemical reactions with Br compounds and it is deposited.

During GEM depletion events dramatically increased levels of both gaseous oxidised mercury (GOM; formerly named reactive gaseous mercury, RGM) and/or PBM_{2.5} are observed (Lu et al., 2001; Lindberg et al., 2002; Lu and Schroeder, 2004; Sprovieri et al., 2005; Steffen et al., 2008). Lindberg et al. (2002) reported the first and highest measured concentration levels of GOM (up to 900 pg/m³) during AMDEs at Barrow (Alaska) and showed a strong correlation between GOM production and UV-B radiation and with increased surface snow Hg concentrations. Calculations of multi-year trends in GOM and PBM_{2.5} at Alert were also performed (Cole et al., 2012), indicating increases from 2002 to 2009 in both GOM and PBM_{2.5} during spring when concentrations are highest.

As previously mentioned (Section 3.4.1.2), ten-year records of TGM were recently analysed from Canadian mid-latitude, sub-Arctic, and High Arctic sites (Cole et al., 2012). The High

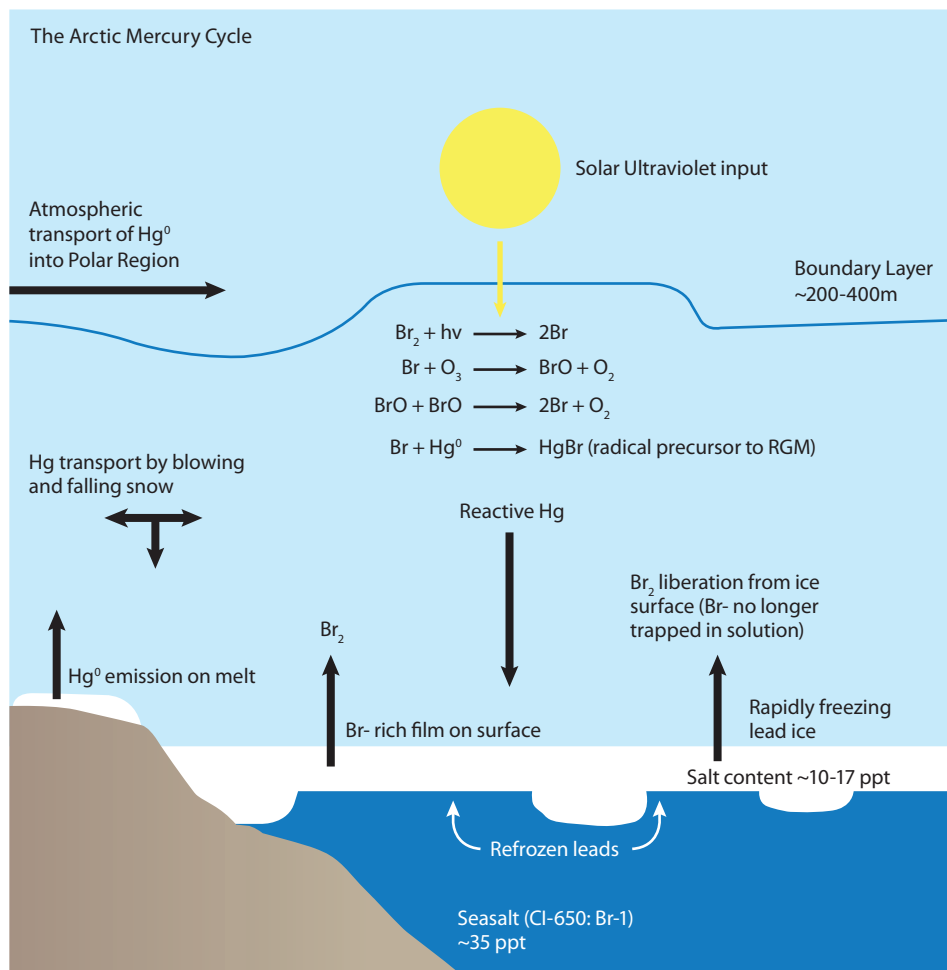


Figure 3.10 Schematic description of atmospheric bromine production and the possible fate of mercury after its chemical reactions with bromine-containing compounds and its deposition. Source: AMAP/UNEP (2008).

Arctic sites examined in that study were Alert (Nunavut, Canada) and Zeppelin station (Svalbard, Norway). At these sites, a different temporal pattern was observed than for the mid-latitude and sub-Arctic sites, given that in the High Arctic, Hg behaves differently with much more variability during the seasons (i.e., springtime chemistry). In particular, no trend has been observed at Zeppelin station whereas in the Canadian High Arctic (Alert) a slight GEM decreasing trend was observed (-0.6% per year). In comparison to the mid-latitudes, this highlights the idea that Hg chemistry is different in the Arctic compared to other parts of the world, both during AMDEs and in terms of long-term behaviour. This may be due to the overlap of several mechanisms, including long-range transport from lower latitudes, and chemical interactions with the sea ice and/or snow pack through surface Br reactions (Simpson et al., 2007; Cole et al., 2012).

Springtime AMDEs have also been observed in Antarctica. During Antarctic spring 2000, Hg ground-level concentrations were measured by Ebinghaus et al. (2002) at Neumayer (70°39'S, 8°15'W), the coastal German Research Station. During the same period enhanced column densities of BrO (GOME satellite data) were observed over the sea ice around the Antarctic continent (Ebinghaus et al., 2002), and enhanced boundary layer BrO concentrations were observed using differential optical absorption spectroscopy (DOAS) (Friess et al., 2001; Dommergue et al., 2010).

3.4.2 Mercury wet deposition measurements and trends

3.4.2.1 Europe

Wängberg et al. (2007) summarised measurements of Hg wet deposition at six EMEP sites along the North Sea coast from 1995 to 2002. On average, a decreasing trend was observed from the first half (1995–1998) to the second half (1999–2002) of the study. On average, the total Hg wet deposition at two sites (Råö and Rörvik) declined substantially over three-year increments from 1987 to 2002, perhaps due to reductions in regional Hg emissions; however changes in meteorological patterns over time could not be assessed or excluded as a factor controlling Hg wet deposition. A slight north-south gradient of increasing concentrations of Hg in precipitation was also reported and may reflect the positions of emission sources in central Europe.

Several atmospheric Hg monitoring sites in Europe, including sites within EMEP, were recently incorporated into the GMOS project. In the future it will be possible to utilise these precipitation measurements to further understand both the spatial and temporal distribution of Hg in wet deposition.

3.4.2.2 North America

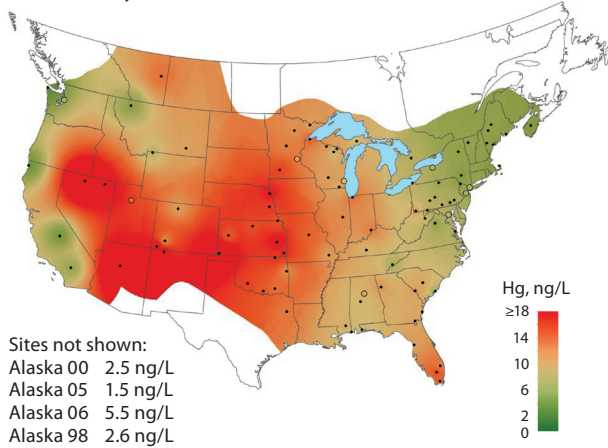
The continued development of Hg monitoring programmes over the past 20 years in the United States and Canada has

provided an opportunity to explore long-term trends in Hg wet deposition. Keeler and Dvonch (2005) presented ten years (1994–2003) of atmospheric Hg observations in the Great Lakes region, where daily-event precipitation samples were collected for Hg and trace elements (Landis and Keeler, 1997). Results from three sites in Michigan (Eagle Harbor, Pellston, Dexter) demonstrated a strong decreasing north-south gradient in the amount of Hg wet deposition. An obvious trend in annual Hg wet deposition over time was not observed, suggesting that despite efforts to control Hg emissions, emission sources in the southern Great Lakes region continually impacted the levels of Hg wet deposition. Similar measurements of event-based Hg wet deposition in the Chicago (Landis et al., 2002; Landis and Keeler, 2002) and Detroit urban areas, as well as the highly industrialised Ohio River Valley (Keeler et al., 2006; White et al., 2009) have further demonstrated the significant contribution from local and regional anthropogenic sources to the observed levels of Hg in wet deposition in the Great Lakes basin. Specifically, 70% of Hg wet deposition in Steubenville (Ohio) was attributed to emissions from coal combustion, based on the application of multivariate statistical receptor models to event-based wet-only measurements of Hg and trace element wet deposition (Keeler et al., 2006). More recently, similar analyses applied to four event-based wet-only monitoring sites in the state of Illinois, also located in the industrialised U.S. Midwest, suggested that coal combustion emissions were responsible for 50–74% of Hg wet deposition at each site (Gratz et al., 2013b).

Prestbo and Gay (2009) recently summarised ten years (1996–2005) of weekly Hg wet deposition measurements from NADP-MDN sites in the United States and Canada. Results indicated regional differences in precipitation, concentration, and deposition over time. Total Hg deposition was highest in the south-eastern United States, and in all regions Hg wet deposition was greatest during the summer. Several sites in the north-eastern United States and along the east coast displayed decreasing trends in concentration (1–2% per year). This trend was not observed in the U.S. Midwest or in much of the southeast. Most Midwest sites displayed no significant trend in concentration or deposition, while several sites in the southeast displayed significant increases in wet deposition. Four sites in the region between the Midwest and northeast United States displayed patterns of decreasing concentration, increasing precipitation amount, and consequently no significant trend in deposition. These varying trends could be attributed to regional differences in meteorology and source emission impacts. Figure 3.11 presents the most recently available total Hg concentration and wet deposition annual gradient maps from the MDN programme for 2011.

Daily-event precipitation samples collected in Underhill (Vermont) from 1995–2006 were analysed for total Hg and trace element concentrations (Gratz et al., 2009; Gratz and Keeler 2011). Measurements from this site comprise one of the longest

Total mercury concentration, 2011



Total mercury wet deposition, 2011

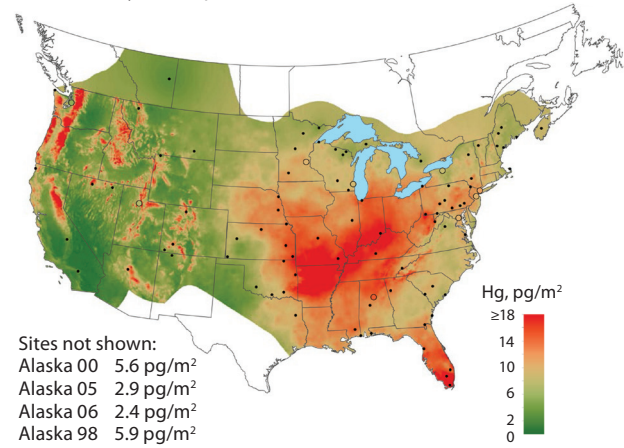


Figure 3.11 Total mercury concentration and wet deposition annual gradient maps for North America from the NADP-MDN programme for 2011. Source: <http://nadp.sws.uiuc.edu/mdn/annualmdnmaps.aspx>.

available Hg wet deposition datasets in the world. A statistically significant trend in annual Hg wet deposition over time was not detected, despite emissions reductions in the United States in the late 1990s with the implementation of stack controls on municipal and medical waste incinerators. In contrast, annual volume-weighted mean (VWM) Hg concentration declined in conjunction with an increase in the total annual precipitation amount. The declines in concentration appeared to be related to local-scale meteorological and climatological variability rather than to a reduction in emissions of Hg to the atmosphere (Gratz et al., 2009). Multivariate and hybrid receptor modelling analyses further revealed that, of the nearly 80% of measured deposition accounted for by the Positive Matrix Factorisation (PMF) multivariate statistical receptor model, coal combustion consistently contributed to approximately 60% of Hg wet deposition. Using back-trajectory cluster analysis and hybrid receptor modelling techniques, the majority of Hg deposition at Underhill was linked to transport from the U.S. Midwest and east coast where the density of coal-fired utility boilers in the United States is greatest (Gratz et al., 2009; Gratz and Keeler 2011).

Risch et al. (2012) recently reported on Hg wet deposition at 37 sites in the North American Great Lakes region from 2002 to 2008. A decreasing trend in Hg concentration was observed at eight sites, and increasing trends in concentration were observed at six sites. Much of the region saw an increase in annual precipitation amount during this period. Over the course of the study, Hg wet deposition was largely unchanged in the Great Lakes region and surrounding areas, and any significant trends in deposition did not correspond with trends in concentration. Overall, it was suggested that any observed declines in concentration were offset by increases in precipitation amount, and as such the total wet deposition amount remained largely unchanged.

These studies revealed regional differences in Hg concentration, precipitation, and Hg deposition patterns in the United States and Canada, and over time a large-scale decline in Hg deposition has not been observed. This overall observation

that Hg wet deposition has not declined over time at many North American locations appears to be somewhat in contrast to the recently reported declines in background GEM concentrations at several remote sites around the world, suggesting that there are still many questions remaining about atmospheric Hg processes, including chemistry, transport, and deposition, at different locations and on different temporal or spatial scales.

Continued long-term monitoring in North America will demonstrate whether new legislation, such as the recently issued Mercury and Air Toxics Standards that regulate Hg emissions from utility boilers and other sources, have a significant impact on the amount of Hg deposited to the environment. In addition, in light of current observations and projected patterns of global climate change, it is plausible that changes in the distribution and intensity of precipitation events may occur. Given that Hg wet deposition amounts vary with geographical location, proximity to emission sources, speciation of emissions, and meteorological conditions prior to and during storm events, it is possible that the spatial distribution in Hg wet deposition will also change with future variability in precipitation patterns and storm intensity. The continued operation of regional and global monitoring networks will allow for investigating these deposition patterns in future climate scenarios.

3.4.2.3 Asia

A summary of total Hg concentrations in precipitation and wet deposition Hg fluxes in Asia is presented in Table 3.6. Total Hg concentrations in precipitation obtained from urban and remote areas of Asia were in the ranges 7.8–30.7 ng/L and 4.0–36.0 ng/L, respectively. Total Hg wet deposition fluxes in urban and remote areas of Asia were in the ranges 13.1–20.2 $\mu\text{g}/\text{m}^2/\text{y}$ and 5.8–26.1 $\mu\text{g}/\text{m}^2/\text{y}$, respectively. Total Hg concentrations in precipitation and wet deposition fluxes in Asia are higher than those observed in urban areas of North America (Landis and Keeler, 1997; Guentzel et al., 2001; Keeler et al., 2006). Total Hg concentrations in urban areas

Table 3.6 Summary of total mercury concentrations in precipitation and atmospheric total Hg deposition fluxes in Asia.

Location	Period	Classification	Precipitation, ng/L	Flux, µg/m ² /y	Source
Chongqing, China	Jul 2010 – Jun 2011	Urban	30.7		Wang et al., 2012a
Guiyang, China	Jul–Sep 2008	Urban	18.0		Liu et al., 2011
Wujiang, China	Jan–Dec 2006	Rural-affected	36.0	34.7	Guo et al., 2008
Mt.Leigong, China	May 2008 – May 2009	Remote	4.0	6.1	Fu et al., 2010a
Mt.Gongga ^a , China	Jan–Dec 2006	Remote	9.9	9.1	Fu et al., 2008b
Mt.Gongga ^b , China	May 2005 – Apr 2007	Remote	14.3	26.1	Fu et al., 2010b
Mt.Changbai, China	Aug 2005 – Jul 2006	Remote	13.4	8.4	Wan et al., 2009b
Japan	Dec 2002 – Nov 2003	Urban	7.8–9.4	13.1–16.7	Sakata and Marumoto, 2005
Japan	Dec 2002 – Nov 2003	Remote	5.0–9.6	5.8–17.7	Sakata and Marumoto, 2005
Seoul, South Korea	Jan 2006 – Dec 2007	Urban	10.1–16.3	16.8–20.2	Seo et al., 2012
Chuncheon, South Korea	Aug 2006 – Jul 2008	Remote	8.8	9.4	Ahn et al., 2011

^a Elevation of the sampling site was 1600 m a.s.l.; ^belevation of the sampling site was 3000 m a.s.l.

of China were much higher than those in Japan and South Korea (Table 3.6). This was mostly attributed to the elevated PBM_{2.5} and GOM concentrations in urban areas, which may be readily scavenged by precipitation.

With the exception of the study in Wujiang, China, total Hg concentrations in precipitation and wet deposition fluxes in remote areas of Asia were comparable to those obtained from the U.S. and Canadian NADP monitoring sites (Prestbo and Gay, 2009). The mean total Hg concentrations and wet deposition fluxes in Wujiang were much higher than other studies in remote areas of Asia (Guo et al., 2008); however, this may be due to the collection of monthly-integrated bulk precipitation samples in those studies, and given the generally elevated levels of ambient PBM_{2.5} and GOM concentrations in China it is likely that dry deposition of PBM_{2.5} and GOM substantially contributed to the total Hg in bulk precipitation samples.

3.4.3 Recent advances in measurement and analytical techniques

In addition to the use of the relatively standard measurement techniques for ambient air Hg and Hg wet deposition across these monitoring networks, a number of new measurement and analytical techniques have also been developed in recent years, which will increase understanding of Hg deposition and environmental cycling patterns. For example, in addition to wet deposition it is known that dry deposition can represent an important fraction of the total deposition of Hg to terrestrial and aquatic ecosystems. But unlike precipitation, dry deposition can be more difficult to measure and at this point in time there is no widely accepted measurement technique. Furthermore, to more fully understand atmospheric Hg chemistry and cycling it

is necessary not only to quantify total Hg dry deposition but also the speciation of Hg in dry deposition. Measurements of dry deposition have been conducted over both natural and surrogate surfaces to try to understand this process. Examples of currently reported methods for directly measuring Hg dry deposition include surrogate water surfaces (Marsik et al., 2007; Hall et al., 2011), leaf washes (Lyman et al., 2007), and cation-exchange membranes (Lyman et al., 2007). Dry deposition of Hg species has also been indirectly quantified using modelling approaches (Lyman et al., 2007; Marsik et al., 2007; Zhang et al., 2012a). Studies to date suggest that the relative contributions from wet and dry deposition to the total Hg deposition can vary greatly by location depending on local emission sources and atmospheric Hg speciation (Lyman et al., 2007). Further developments in existing measurement techniques, as well as model-measurement comparison, is needed in order to better understand temporal and spatial patterns in Hg dry deposition.

Additionally, there have been efforts recently to develop passive samplers for measuring atmospheric Hg. Availability of such techniques could make it possible to measure atmospheric Hg with reduced power and financial constraints. Examples of more recently reported techniques are mercury vapour adsorption tubes (Brown et al., 2012), and a passive sampler for TGM containing either gold plates or silver wires in an expanded PTFE housing (Gustin et al., 2011). Further method developments of this type are anticipated in the future so that passive sampling methods could be applied on a broader scale.

There is also growing interest in developing new analytical techniques for quantifying Hg in environmental samples. For example, measurements of Hg stable isotope geochemistry have been developed in recent years as a tool for studying Hg

biogeochemical cycling (Bergquist and Blum, 2009). Mercury has seven stable isotopes, active redox chemistry, an ability to form covalent bonds, and it commonly transforms between the solid, aqueous, and gas phases. These characteristics allow for significant variations in Hg isotopic composition to be observed across natural samples. Mercury has been observed to undergo both mass-dependent and mass-independent fractionation in a variety of environmental samples, and variations in these signatures may offer insight into Hg biogeochemistry (Bergquist and Blum, 2009, and references therein). Although this is a relatively new area of study, it is one that is growing rapidly. Results published to date suggest that further investigation of this technique will continue to provide insight into atmospheric Hg sources and chemistry (Bergquist and Blum, 2007, 2009; Gratz et al., 2010; Sonke, 2011; Sherman et al., 2012).

3.5 High altitude mercury measurements

3.5.1 High altitude ground-based monitoring stations

In recent years, high-altitude measurements of atmospheric Hg have been reported for the Mt. Bachelor Observatory, Oregon (2700 m a.s.l.) (Jaffe et al., 2005; Swartzendruber et al., 2006; Weiss-Penzias et al., 2006, 2007; Finley et al., 2009), the Storm Peak Observatory, Colorado (3220 m a.s.l.) (Obrist et al., 2008; Fäin et al., 2009) and sites in Nevada, USA (Weiss-Penzias et al., 2009), as well as the Lulin Atmospheric Background Station in Taiwan (2862 m a.s.l.) (Sheu et al., 2010). Weiss-Penzias and colleagues are preparing a comparison of observations from these high elevation sites to identify similar patterns in the observations. Furthermore they have also compared observations with results from the GEOS-CHEM global Hg model. Results suggest that all of these high elevation sites show a common negative relationship between GEM and GOM. The strength of this relationship in the observations varies depending on the site, whereas the model shows a strong relationship at all sites. This systematic difference can be used to understand the behaviour and oxidation of Hg at high elevations. Furthermore, a new analysis from the Mt. Bachelor Observatory suggests that there are additional mechanisms to generate GOM in the free troposphere, which include oxidation within anthropogenic pollution plumes and escape from the marine boundary layer (Timonen et al., 2012).

Speciated atmospheric Hg has also been measured at the Mauna Loa Observatory in Hawaii, where continuous measurements of several important species have been collected since the 1950s. Mauna Loa is a high altitude monitoring station (3397 m a.s.l.) managed by the U.S. National Oceanic and Atmospheric Administration (NOAA).

Measurements of speciated atmospheric Hg began in 2001 and are managed by the U.S. Environmental Protection Agency (EPA). Together with speciated Hg, this monitoring effort has also included continuous measurements of ozone, sulphur dioxide, elemental carbon, and other important atmospheric constituents. Mauna Loa, Mt. Bachelor, Storm Peak, the Lulin Atmospheric Background Station, and other previously mentioned high-altitude stations in Asia are also being included in the GMOS ground-based monitoring network, which will allow an in-depth investigation into Hg transport on the global scale through the integration of these high-quality, long-term monitoring datasets.

Within GMOS, several new high-altitude monitoring stations for atmospheric Hg have also been established. In November 2011, the Institute of Atmospheric Pollution Research of the National Research Council of Italy (CNR-IRA) installed a Tekran 2537A Mercury Vapour Analyser at the Ev-K2-CNR Pyramid International Laboratory in the eastern Himalaya Mountains of Nepal. The Pyramid Laboratory (27.95°N, 86.82°E; 5050 m a.s.l.) is a high altitude Italian scientific research centre in Nepal's Khumbu Valley near the Mt. Everest base camp. In April 2012, the Tekran analyser was relocated to the nearby, newly renovated Nepal Climate Observatory at the Pyramid (NCO-P), approximately 200 m from the Pyramid at 5079 m a.s.l. Currently this is the highest altitude monitoring station for atmospheric Hg in the world. Preliminary analyses of TGM measurements from November 2011 to April 2012 suggest that the mean TGM concentration was 1.2 ng/m³ (range 0.7–2.6 ng/m³) (Gratz et al., 2012). The data from this location will provide valuable information on the levels of atmospheric TGM in the free troposphere, and in a region of the world where atmospheric Hg measurements are limited but meteorological influences on air quality have previously been observed (Bonasoni et al., 2010).

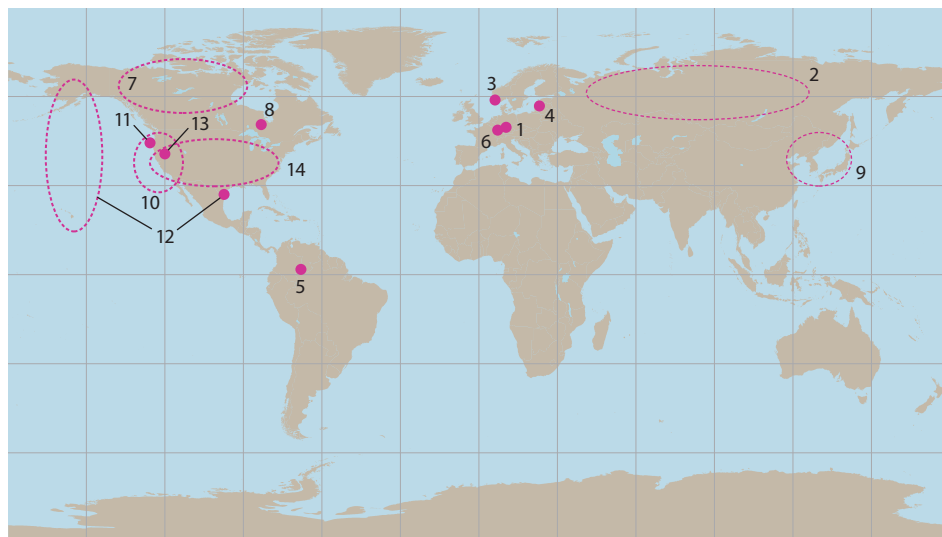
Another interesting addition to the GMOS network has been the French-Italian base, Dome Concordia Station (Dome-C) in Antarctica. Measurements of GEM using the Tekran 2537 Mercury Vapour Analyser began at Dome C (75°06'S, 123°20'E, 3320 m a.s.l.) in December 2011. Dome C is located on the Antarctic plateau, 1100 km from the east Antarctic coast. Monitoring of GEM at Dome-C has already shown some unique results and a surprising level of reactivity (Dommergue et al., 2012). The observed behaviour and trends will be examined more closely as the dataset at this unique site continues to develop. The addition of sites such as Dome C and Ev-K2-CNR to the GMOS network will contribute greatly to the investigation and understanding of atmospheric Hg on the global scale.

3.5.2 Aircraft measurements

3.5.2.1 Campaign-based aircraft measurements

Because Hg is globally distributed through the atmosphere, aircraft observations are a key component for understanding

Figure 3.12 Approximate locations of all known aircraft-based airborne Hg measurements around the world to 2011 (except CARIBIC). Source: Ebinghaus et al. 2012 (and references therein).



- | | |
|-------------------------------|--|
| 1 Slemr et al., 1985 | 8 Friedli et al., 2003 |
| 2 Kvietkus et al., 1985, 1995 | 9 Friedli et al., 2004 |
| 3 Brosset, 1987 | 10 Radke et al., 2007 |
| 4 Kvietkus et al., 1995 | 11 Swartzendruber et al., 2008 |
| 5 Artaxo et al., 2000 | 12 Talbot et al., 2008 |
| 6 Ebinghaus and Slemr, 2000 | 13 Swartzendruber et al., 2009 |
| 7 Banic et al., 2003 | 14 http://www.atmos.washington.edu/jaffegroup/modules/NAAMEX/ |

the vertical distribution. Given that airborne Hg measurements are highly demanding and challenging, relatively few airborne Hg measurements have been carried out. The introduction of the automated Tekran instrument enabled the first highly resolved aircraft measurements of the spatial distribution of Hg in the atmosphere (Ebinghaus and Slemr, 2000; Banic et al., 2003; Friedli et al., 2003). Figure 3.12 shows the approximate location of all known airborne Hg measurements around the world, which were obtained on 14 individual measurement aircraft campaigns and published between 1976 and 2009. Many of these measurements were made as individual campaigns with specific objectives and are thus limited in region and time.

Most aircraft measurements have considered only GEM or TGM (Banic et al., 2003; Ebinghaus et al., 2007; Talbot et al., 2008; Slemr et al., 2009; Swartzendruber et al., 2009 and references therein). A summary of the vertical Hg profiles published in the peer-reviewed literature are summarised in Figure 3.13 (Swartzendruber et al., 2009). The vertical gaseous Hg distribution (TGM and GEM) is more or less constant with concentrations ranging from 0.5 to 2.0 ng/m³.

Very recently, new instrumentation has been developed to measure oxidised Hg compounds as well (Lyman and Jaffe, 2012). Measurements of total Hg, GOM, and O₃ were collected during a flight across the Great Lakes region of the US, in which the aircraft encountered a tropospheric fold with high concentrations of GOM. The results demonstrate that aircraft can be used to measure the complete suite of Hg species in the atmosphere.

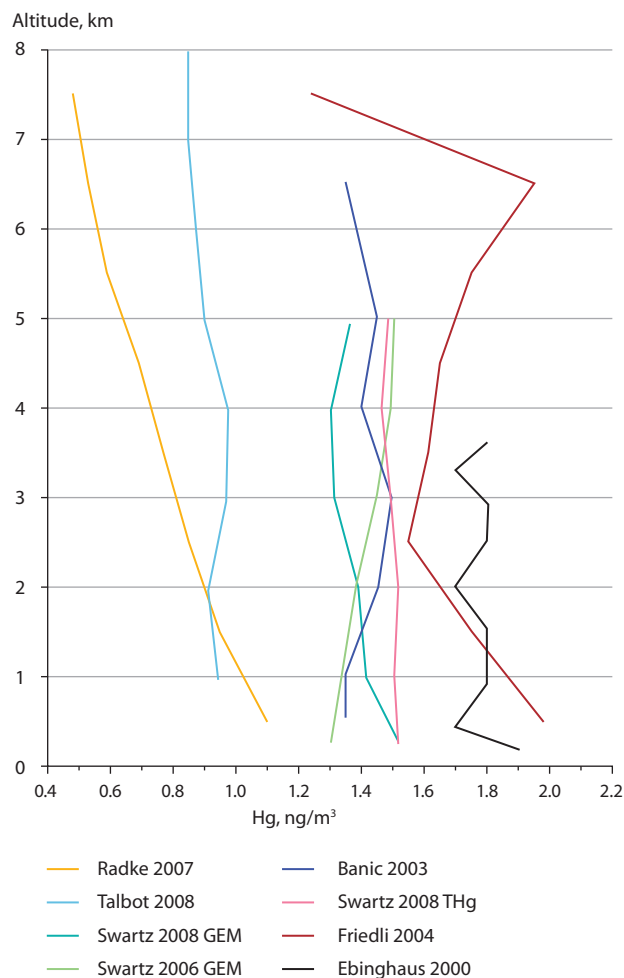


Figure 3.13 Comparison of known vertical gaseous mercury profiles (TGM and GEM). Source: Swartzendruber et al., 2009 (and references therein).

3.5.2.2 The European CARIBIC project

CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container) is a scientific project designed to study and monitor important chemical and physical processes in the Earth's atmosphere over the long-term. Detailed and extensive measurements of atmospheric gases and trace compounds are made during long distance flights by a commercial passenger aircraft (Airbus A340-600; 'Leverkusen'). CARIBIC deploys an airfreight container with automated scientific apparatus connected to an air and particle (aerosol) inlet under the aircraft (Brenninkmeijer et al., 2007). In addition to these campaign-based aircraft measurements, monthly intercontinental CARIBIC flights since May 2005 have generated detailed measurements of the large-scale distribution of atmospheric Hg (Ebinghaus et al., 2007; Slemr et al., 2009). The typical monthly measurement sequence includes four intercontinental flights with a total flight time of about 40 hours (Figure 3.14).

The container holds automated analysers for TGM, CO, O₃, NO, NO_y, CO₂, total and gaseous water vapor, oxygenated organic compounds, fine particles (three counters for particles with diameters > 4 nm, > 12 nm, and > 18 nm), an optical particle counter for particles > 150 nm, and instruments for continuous measurements of water isotopologues and methane (CH₄). Up to 116 whole air samples and 16 aerosol samples are also collected. Air samples are later analysed for greenhouse gases (Schuck et al., 2009), hydrocarbons (Baker et al., 2010), and halocarbons (Oram et al., 2012), while aerosol samples are analysed for their morphology and elemental composition (Nguyen et al., 2008). Mercury is measured by a Tekran 2537 analyser. The inlet tubing is PFA-lined and consists of high-volume circular tubing with a temperature regulated manifold

(40 °C) and a short PFA connection to the instrument at the internal container temperature (about 30 °C). For operation at cruise altitudes around 10 km the air sample is compressed from ambient pressure to about 500 hPa (needed to operate the Tekran instrument with its internal pump). At present the Tekran is operated using a 10 minute sampling interval to obtain a detection limit and precision of ~0.05 ng/m³. Reported results are corrected (Slemr et al., 2009) at standard temperature and pressure.

Since May 2005, almost 300 intercontinental flights have provided Hg measurements in the upper troposphere and lower stratosphere (Slemr et al., 2012). TGM concentrations are always lower in the lower stratosphere than the upper troposphere. In both locations, TGM behaves in a similar manner to other trace species with ground sources and stratospheric sinks (e.g., CO and CH₄) but, unlike these other species, Hg can only be transformed into other Hg species (i.e., PBM_{2.5}) which escape detection by the analytical instrumentation. High PBM_{2.5} concentrations together with high particulate Br concentrations in the lower stratosphere were reported by Murphy et al. (1998, 2006). An attempt to quantify Hg on the aerosol samples collected during the CARIBIC flights was unsuccessful because the semi-volatile Hg compounds on the particles are pumped away during analysis in vacuum by proton-induced X-ray emission, perhaps suggesting that TGM is more likely to be converted to semi-volatile Hg halogenides (e.g., HgBr₂, HgCl₂) than to much less volatile HgO. An inverse relationship between TGM and particle concentration has also been observed in the deep stratosphere (Slemr et al., 2012).

The transformation rate of TGM to PBM_{2.5} can be calculated using the long-lived tracer SF₆. Correlations of TGM with SF₆ suggest a seasonally dependent TGM conversion rate of about 0.43 ng/m³/y resulting in a stratospheric TGM lifetime of about 2 years. This lifetime is longer than the several weeks

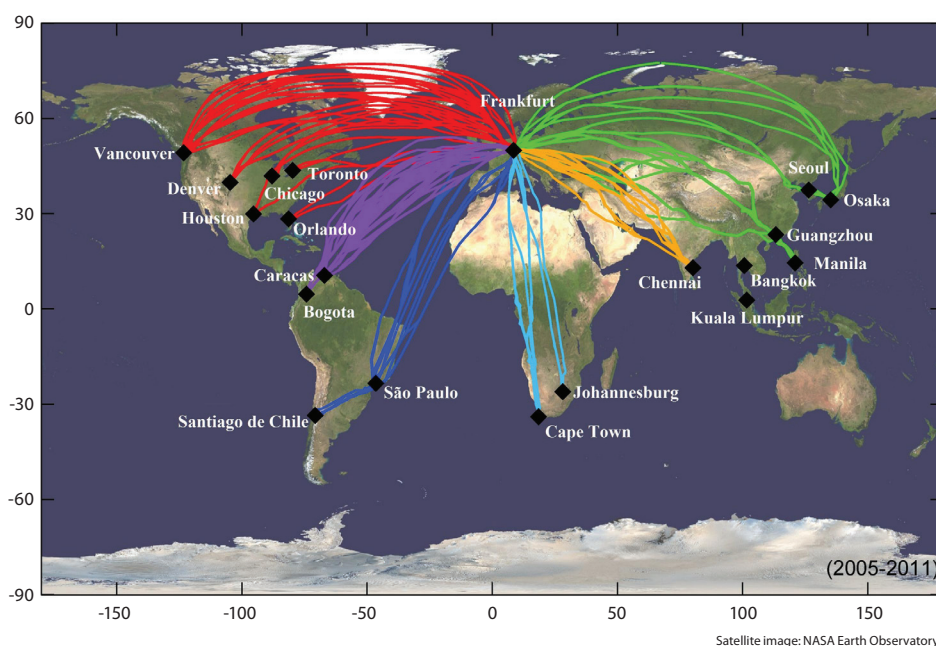


Figure 3.14 Intercontinental flight tracks of the CARIBIC project between 2005 and 2011. Source: www.caribic-atmospheric.com.

recently suggested by Lyman and Jaffe (2012) and possibly closer to the lifetime of 1 year estimated by Holmes et al. (2010a) using the GEOS model with Br oxidation chemistry (Slemr et al., 2012).

3.6 Global mercury modelling

3.6.1 Introduction

The transport and deposition of Hg depend to a very great extent on its oxidation state. As previously mentioned, GEM in the atmosphere generally oxidises relatively slowly, it deposits slowly because of its high (for a metal) vapour pressure and due to its low solubility it is inefficiently scavenged by cloud droplets and precipitation. On the other hand, GOM compounds deposit rapidly and are efficiently scavenged due to the higher solubility of GOM. Hence GEM is subject to long-distance transport, whereas GOM is, for the most part, dry or wet deposited close to the point of emission or formation. Mercury also exists in the atmosphere associated with particulate matter, either as a component of the particulate itself or adsorbed onto the particulate, and in equilibrium with the Hg and its compounds present in the gas phase.

When modelling the transport and deposition of Hg it is necessary to have a good understanding of the speciation of Hg emissions. It is equally important that the chemistry of the atmosphere is accurately represented in terms of the potential oxidants of Hg, because as already mentioned it is the oxidation state of Hg which determines how far it is transported and how rapidly it is deposited. However as discussed in Section 3.2 there are still some fundamental uncertainties in understanding of atmospheric Hg chemistry. Modelling studies involving Hg range from process modelling where detailed physico-chemical models are employed to study the mechanisms involved in individual processes, to regional transport and chemistry models where relatively high spatial resolution models are used to investigate regional-scale Hg deposition and concentration variations, to global models used to investigate long-range Hg transport and deposition patterns and their long-term variation. The importance of global models has become more evident recently as assessments of regional modelling studies have highlighted the importance of the choice of boundary conditions for the modelling domain. It is now accepted that regional models require boundary (and initial) conditions supplied by the output from global models. The following parts of Section 3.6 discuss the approaches used in global and regional models to represent the atmospheric processes influencing Hg transport and deposition.

Atmospheric chemical transport models are powerful tools for assessing pollution levels and transport pathways for environmental contaminants, given the limited coverage of existing monitoring networks. Contemporary Hg models

complement direct measurements by providing spatial coverage and detailed information on ambient concentrations and deposition levels, estimates of source attribution, an explanation of historical trends and projections of future changes in pollution. The models can also be used in combination with measurement data to investigate the physical and chemical processes controlling the fate of Hg in the atmosphere as well as to evaluate emission inventories.

3.6.2 Global patterns of mercury air concentration and deposition

The global distribution of atmospheric Hg concentrations and deposition were simulated using an ensemble of contemporary models within the HTAP multi-model experiment (Travnikov et al., 2010). The results show (Figure 3.15a) that the highest GEM concentrations ($> 2 \text{ ng/m}^3$) are characteristic of major industrial regions – East and South Asia, Europe, North America, and South Africa. There is also a pronounced gradient in the surface GEM concentrations between the southern and northern hemispheres owing to the positions of major anthropogenic emission sources.

Deposition of atmospheric Hg is mostly the result of wet scavenging and dry deposition of the oxidised forms (GOM and $\text{PBM}_{2,5}$). Depending on the origin of these Hg species, the deposition flux can be divided into two components:

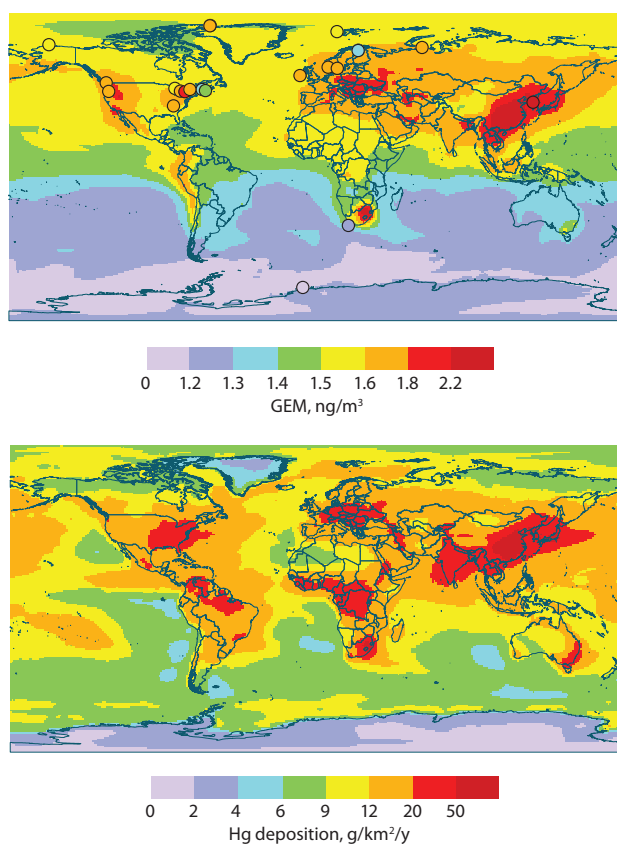


Figure 3.15 Global distribution of ensemble mean annual GEM concentration in ambient air (a) and annual mercury total deposition (b) in 2001. Circles represent long-term observations from the AMAP, EMEP, CAMnet networks and at some other monitoring sites. Source: Travnikov et al. (2010) and references therein.

the first consists primarily of emitted short-lived forms; the second is defined by oxidation of GEM in the atmosphere. The former is prevalent in the vicinity of emission sources, whereas the latter dominates in remote regions. An additional process contributing to Hg deposition is air-surface exchange (mainly associated with vegetated surfaces) of GEM. All these mechanisms are reflected in the simulated global Hg deposition pattern (Figure 3.15b). High Hg deposition fluxes were obtained in major industrial regions and over some remote areas characterised by high precipitation. In general, deposition fluxes are higher in low to mid-latitudes because of higher concentrations of the main oxidants and precipitation amount. Elevated deposition levels are also characteristic of the polar regions due to AMDEs during the spring. The lowest

deposition fluxes occur inland in Antarctica and Greenland.

Estimates of annual Hg deposition to various land and water surfaces globally are given in Table 3.7.

The models differ considerably in their estimates of total deposition in particular regions. Smaller differences (below a factor of 2) are characteristic of the industrial regions largely affected by local anthropogenic sources, whereas the largest discrepancies (a factor of 3 or more) are over remote regions and regions with small anthropogenic emissions. The main differences in the model results are explained by the different approaches used in the spatial distribution of natural emissions and re-emissions, the major oxidants of GEM in the atmosphere and the reaction products included in the models (AMAP, 2011).

Table 3.7 Modelled Hg deposition to various world regions and ocean basins in 2005, t/y.

	GRAHM	GEOS-Chem	GLEMOS	CMAQ-Hg ^a	DEHM ^a
Deposition to land					
Sub-continent					
Australia, New Zealand & Oceania	97	155	57	-	-
CIS & other European countries	346	418	220	193	198
Central America and the Caribbean	44	60	27	49	17
EU27	102	104	58	71	63
East and Southeast Asia	490	524	381	420	334
Middle Eastern States	70	89	29	59	31
North Africa	53	54	16	28	13
North America	317	420	208	197	169
South America	274	443	227	-	-
South Asia	132	164	90	-	-
Sub-Saharan Africa	331	516	249	-	-
Total	2256	2947	1562	1018	825
Deposition to oceans					
Ocean basin					
Antarctic	45	35	11	-	-
Arctic	216	304	163	65	133
Atlantic	648	1410	919	1063	318
Baltic	12	14	8	7	7
Black Sea	13	18	11	12	10
Caspian Sea	6	10	7	5	3
Indian	525	1343	689	646	112
Mediterranean	42	49	34	41	29
North Sea	14	18	11	12	11
Pacific	1358	2733	1767	1576	657
Total	2878	5934	3619	3425	1280

^a Northern hemisphere only.

3.6.3 Estimates of mercury intercontinental transport

The impact of intercontinental atmospheric transport of Hg on regional contamination levels was studied by Travnikov et al. (2010). The four models involved in the study differed significantly in their formulation of atmospheric transport, chemistry, and natural and secondary emissions. In spite of considerable differences in deposition estimates, the participating models were consistent in their source attribution. Typically domestic sources make the largest contribution (15–55%) to Hg deposition in respective regions. The contribution of foreign anthropogenic sources to annual Hg deposition fluxes varies from 10% to 30% on average anywhere on the globe (Figure 3.16). Where domestic sources are low their contribution to deposition can be less than that from foreign sources (Travnikov et al., 2010). Among the major contributors, East Asia is the most dominant source region, with annual contributions from anthropogenic sources of 10–14% to Hg deposition in other regions. Natural and secondary emissions contribute 35–70% of total deposition to most regions.

These results shown in Figure 3.16 are generally consistent with findings from previous model studies. Seigneur et al.

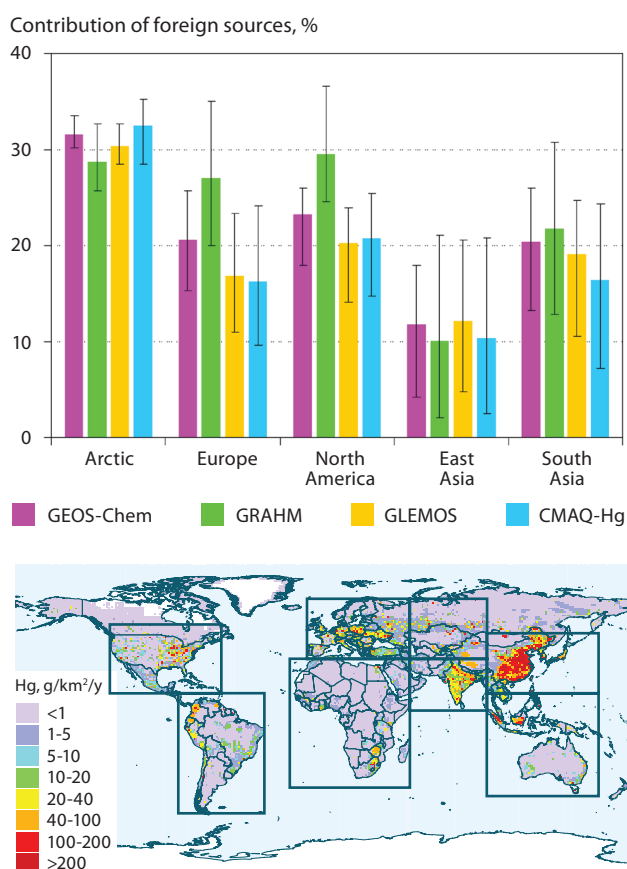


Figure 3.16 (a) Contribution of foreign anthropogenic sources to mercury deposition in different receptor regions in 2005. Bars represent average values and whiskers show the 90%-confidence interval of the parameter variation over a region. (b) Global distribution of anthropogenic mercury emissions in 2005 and location of source regions considered in the analysis – Europe, North America, East Asia, South Asia, Central Asia, Africa, South America, Australia and Oceania. Source: Travnikov et al. (2010).

(2004) found that North American anthropogenic emissions contributed 25–30% and Asian anthropogenic emissions about 20%, to Hg deposition in the United States. Travnikov and Ilyin (2005) estimated that around 40% of annual Hg deposition to Europe originated from distant sources (Asia 15%, North America 5%). The same study indicated that North America is particularly affected by emission sources on other continents, with up to 67% of total deposition from foreign anthropogenic and natural sources (Asia 24%, Europe 14%). More recent results obtained with a coupled land–ocean–atmosphere model (Selin et al., 2008; Corbitt et al., 2011) distinguished between natural emissions and re-emissions to Hg deposition over the United States. Present-day Hg deposition in the United States includes about 20% from primary anthropogenic emissions in North America, 22% from primary anthropogenic emissions outside North America (mostly East Asia), 26% from recycling via land and oceans, and 32% from natural origins.

The above-mentioned models were also employed to investigate Hg pollution in the Arctic (AMAP, 2011). The model ensemble results indicated that the largest anthropogenic contribution to Hg deposition in the Arctic is from East Asia followed by Europe, Central and South Asia, and North America. However, all present-day anthropogenic emissions contribute approximately one-third of total Hg deposition to the Arctic and the other two-thirds are made up by natural sources and re-emissions.

3.6.4 Evaluation of future scenarios

Global Hg models are also used for projecting future emissions scenarios (Travnikov et al., 2010; Corbitt et al., 2011). Possible future changes in Hg pollution levels were simulated by an ensemble of four global and hemispheric models on the basis of three emission scenarios for 2020 (Travnikov et al., 2010). The scenarios represent the status quo conditions (current patterns, practices and uses continue, while economic activity increases in various regions; the ‘SQ’ scenario); economic progress, and wide implementation of emission control technologies currently used throughout Europe and North America (the ‘EXEC’ scenario), and implementation of all feasible control technologies to reduce Hg, leading to the maximum degree of emissions reduction (the ‘MFTR’ scenario) (AMAP/UNEP, 2008). The model ensemble projected consistent changes in levels of Hg deposition in the future. Depending on the emissions scenario applied, Hg deposition is projected to increase by 2–25% (for SQ) or decrease by 25–35% (for EXEC and MFTR) in different industrial regions. In remote regions, such as the Arctic, the changes are expected to be smaller, ranging from an increase of 1.5–5% (SQ) to a decrease of 15–20% (EXEC, MFTR).

Corbitt et al. (2011) applied a global atmospheric model with coupled surface reservoirs to quantify source-receptor relationships on continental scales for the present-day and for 2050 emissions projections (Streets et al., 2009). The

projections are based on four emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) (A1B, A2, B1, B2) distinguished by their assumptions regarding industrial growth, energy policy, and emissions control. The worst-case scenario (A1B) assumes heavy use of coal with limited emission control technology, while the best-case scenario (B1) assumes aggressive transition away from fossil fuel energy sources and implementation of efficient control technology. The models results suggest that Hg deposition in 2050 relative to present day is similar in the B1 scenario but increased in the three other scenarios, reflecting the global trend in emissions. In addition, an increasing fraction of HgII in total Hg emissions in the future will result in an increasing relative domestic contribution to deposition (Figure 3.17).

3.6.5 Overview of modelling approaches

Most transport models consider the full chain of Hg processes in the atmosphere: emission from anthropogenic and natural sources/processes, atmospheric transport, chemical transformations, and deposition to terrestrial and oceanic surfaces. The models consider a number of gaseous mercury forms (GEM and GOM) as well as Hg species dissolved in cloud water and Hg bound to particles (PBM_{2.5}). Simulated redox chemistry includes Hg reactions with such atmospheric oxidants as O₃, OH, H₂O₂, and/or reactive halogens (Br, BrO, Br₂, Cl, ClO, Cl₂, etc.) (Holmes et al., 2010a; Travnikov et al., 2010; Lin et al., 2012). Most models incorporate oxidation reactions driven by all or some of these substances in their

chemical schemes. For instance, oxidation reactions of GEM with O₃ and OH were considered to be the major oxidation mechanisms during the past decade, and allowed reproduction of observed Hg concentrations and wet deposition fluxes on both regional and global scales (e.g., Seigneur et al., 2004; Ryaboshapko et al., 2007a,b; Selin and Jacob, 2008; Travnikov and Ilyn, 2009). However, these chemical mechanisms failed to simulate fast Hg⁰ oxidation during AMDEs and the diurnal cycle of GOM concentrations in the marine boundary layer (Selin et al., 2007). On the other hand, there has been a successful effort to explain the whole gas-phase Hg oxidation chemistry in the free atmosphere solely in terms of reaction with atomic Br (Holmes et al., 2010a; Amos et al., 2012).

Atmospheric Hg removal processes include scavenging by precipitation (wet deposition) and deposition through interaction with the earth's surface (dry deposition). Wet deposition is commonly distinguished in terms of in-cloud and below-cloud washout and involves oxidised forms of Hg (GOM, PBM_{2.5}). GEM does not undergo direct scavenging by precipitation because of its low solubility, but it can be washed out indirectly through dissolution and oxidation in cloud water. Some Hg transport models include explicit treatment of Hg cycling in environmental media other than the atmosphere such as soil, vegetation, snow, sea and freshwater bodies (Selin et al., 2008; Smith-Downey et al., 2010; Soerensen et al., 2010; Durnford et al., 2012).

A number of intercomparison studies have been performed during the last decade to analyse model differences and to quantify uncertainties in the results produced by various models (Ryaboshapko et al., 2007a,b; Bullock et al., 2008, 2009). The most

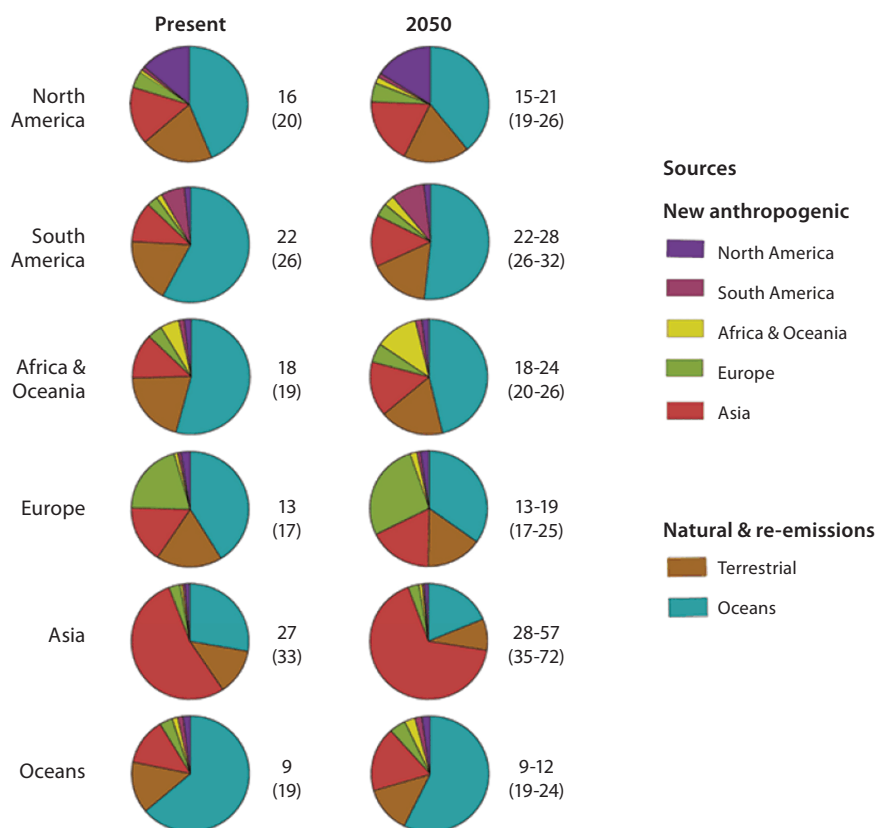


Figure 3.17 Sources of mercury deposited to aggregated world regions for the present-day and for 2050 based on four IPCC emissions scenarios (A1B, A2, B1, B2). Numbers give annual net deposition fluxes to the receptor region (gross deposition fluxes in parentheses) and for 2050 represent the range of the IPCC scenarios. Pie charts show the relative source contributions to deposition. Source: Corbitt et al. (2011).

recent intercomparison was organised within the framework of the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) under the UN Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) and carried out a multi-model evaluation of intercontinental transport of different air pollutants, including Hg, using mainly global and hemispheric models (Pirrone and Keating, 2010; Travníkov et al., 2010). The estimated magnitudes of model uncertainties range from 20%, for the simulated air concentration of GEM, to 80% for the simulated total deposition. However, the model results for the relative source attribution have a smaller uncertainty at about 30%.

3.7 Regional mercury modelling

3.7.1 Introduction

Regional-scale Hg models are necessary to look more closely at areas of particular interest, and the higher spatial resolution employed enables these models to simulate the dispersion and deposition of Hg more accurately than global models.

Local-scale/urban models are employed for investigating Hg concentration and deposition in the immediate vicinity of large emission sources where the influence of regional and global Hg transport is relatively insignificant. These models are Gaussian type or plume models that employ pollutant transport and dispersion from a single emission source and include chemistry and removal processes (Lohman et al., 2006). Regional or continental-scale models address atmospheric dispersion and transport within a continent or a specific region containing numerous emission sources. Most regional Hg models are Eulerian systems that simulate the emission, transport, chemistry and deposition of Hg in three dimension using a fixed grid structure (Cohen et al., 2004; Hedgcock et al., 2006; Pan et al., 2006; Roustán and Bocquet, 2006; Voudouri and Kallos, 2007; Travníkov and Ilyin, 2009). Ambient air Hg concentrations and deposition on regional scales are determined both by regional emissions of Hg and by Hg transported globally. Regional models offer finer horizontal resolution (10–50 km) compared to the generally coarse resolution of global models (100–1000 km) and thus are suitable for detailed examination of Hg distribution within a region. Detailed information on meteorology, chemistry and emissions is often used in these models. Since Hg transports on a global scale, regional Hg models are not self-contained and require initial and lateral boundary conditions of Hg concentration. These concentrations are typically assigned as fixed background values or values extracted from the global Hg model simulations. One problem with this approach is that the regional and global models often use different meteorology, Hg emissions and parameterisations for chemistry and deposition. Use of different global models to define boundary conditions can generate variations in regional patterns of atmospheric Hg concentration, as well as wet and

dry deposition (Bullock et al., 2008, 2009; Pongprueksa et al., 2008; Myers et al., 2012). A few nested grid regional models have been developed that make use of a common model to provide simulations at global and regional resolutions using a multi-scale approach (e.g., Zhang et al., 2012b).

3.7.2 Mercury model intercomparison studies

The most comprehensive Hg model intercomparison study to date – NAMMIS (North American Mercury Model Intercomparison Study) – was conducted for North America using three regional models (Bullock et al., 2008, 2009). The study compared the regional Hg models CMAQ-Hg (Community Multi-scale Air Quality model), REMSAD-Hg (Regional Modelling System for Aerosols and Deposition) and TEAM (Trace Element Analysis Model) with each other and with the Hg wet deposition measurements applied in a tightly constrained testing environment, thus allowing a better analysis of the impact of differences in model Hg process parameterisations on the simulations. The three regional models used the same emission inventory data, meteorological fields and initial/boundary conditions as model input. The Hg distributions simulated by three global Hg models, CTM-Hg (Chemical Transport Model for Hg; Shia et al., 1999), GEOS-Chem (Selin et al., 2007) and GRAHM (Global-Regional Atmospheric Heavy Metals Model; Dastoor and Larocque, 2004), were used to specify the initial/boundary conditions for the regional models. MDN Hg wet deposition measurements since the 1990s (Vermette et al., 1995) and from event-based monitoring at the Proctor Maple Research Center near Underhill, Vermont (Keeler et al., 2005) were used to validate the models.

The differences in air concentration of Hg species simulated by the three regional models led to significant differences in the mass balance of Hg fluxes in the domain. Model simulated wet deposition of Hg was strongly influenced by the shared precipitation input, but differences of over 50% were still present. Different formulations of dry deposition parameterisations and Hg speciation resulted in differences of up to a factor of ten in some locations between the models. The study also found that Hg concentration patterns generated by the regional-scale models can be significantly different even when the same initial/boundary condition datasets were used.

Observations show that the greatest Hg deposition flux occurs during summer with the lowest during winter. The models generally reproduce this seasonal pattern regardless of the boundary conditions used. The spring and summer seasons present the most difficulty in simulating wet deposition of Hg perhaps because of largely convective precipitation in North America during these seasons which is harder to predict by the meteorological simulation on which the air-quality models rely to estimate wet deposition. The regional models were able to resolve 45–70% of the observed site-to-site variation in annual Hg wet deposition.

3.7.3 Investigation of Hg contamination in specific regions

Several regional-scale Hg models have been developed and applied for simulations of Hg atmospheric transport and deposition in Europe. An air-seawater coupled regional model (MECAWEx) was used for simulating Hg cycling in the Mediterranean region by Hedgecock et al. (2006). The model output showed that Hg evasion from the sea surface significantly exceeds total (wet and dry) deposition making the Mediterranean Sea a net emitter of Hg. They also found that dry deposition generally exceeds wet deposition in Mediterranean region. A coupled regional/hemispheric Hg modelling system (MSCE-HM) was developed by Travníkov and Ilyin (2009) for operational simulations of transboundary Hg pollution within Europe. They found systematically elevated TGM concentrations (1.6–2 ng/m³) and wet deposition fluxes (10–20 µg/m²/y) in central and southern Europe.

A comprehensive regional Hg model based on the US EPA's Community Multi-scale Air Quality (CMAQ) modelling system for North America was developed by Bullock and Brehme (2002) and recently revised by Baker and Bash (2012). Various versions of CMAQ-Hg have been applied to study Hg processes, distribution, budgets and source attribution in United States (Lin and Tao, 2003; Gbor et al., 2006; Lin et al., 2006, 2007; Sillman et al., 2007). A multi-scale modelling system consisting of a global chemical transport model for Hg (CTM-Hg) and a nested regional model (TEAM) was also applied to estimate Hg deposition over the contiguous United States (Seigneur et al., 2004). Mercury deposition to the Great Lakes was studied in detail with the Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT) (Cohen et al., 2004). Zhang et al. (2012b) and Lin et al. (2012) conducted the most recent survey of Hg contamination and source attribution for the United States.

Zhang et al. (2012b) used a high-resolution (0.5° latitude × 0.6° longitude; 40 vertical levels up to 10 hPa) nested grid regional version of the GEOS-Chem global model for North America. The Hg emissions, meteorology, chemistry and deposition are self-consistent between the regional and global domains of the model. They showed that the nested grid model is better at capturing the high spatial and temporal variability of Hg wet deposition over North America compared to the low resolution global version of the model. They also investigated the source attribution of Hg deposition in North America. The results were found to be highly sensitive to the assumed speciation ratio of anthropogenic emissions. With an assumption of a significantly lower ratio of oxidised Hg compared to GEM in the emissions (in-plume reduction), the North American anthropogenic sources contributed to only 10% of the total Hg wet deposition in the United States, compared to 22% in the base simulation. Although there is consistent evidence from several modelling studies that an assumption of in-plume reduction improves the modelling

estimates of ambient oxidised Hg concentrations and wet deposition, the reduction mechanism itself is currently unknown (Lohman et al., 2006; Amos et al., 2012; Kos et al., 2012; Zhang et al., 2012b). In contrast, a study by Kolker et al. (2010) measuring speciated Hg in the ambient air at multiple distances downwind from emissions sources found increasing concentration of HgII downwind. See Section 3.2 for a discussion of the assumption regarding in-plume reduction.

Recently, Lin et al. (2012) conducted an extensive source attribution study using CMAQ-Hg for the six sub-regions of the contiguous United States (CONUS) to explore the benefits of the maximum available control technology (MACT) rules proposed by the U.S. EPA. They found that dry deposition accounts for two-thirds of total annual deposition in CONUS, mainly contributed by GOM (about 60% of total deposition). Figure 3.18 shows the relative contribution of different source sectors to Hg deposition in each sub-region on an annual basis. The Hg transport from outside the CONUS region contributes from 68% (Northeast region) to 91% (West Central region) of total deposition. Large point sources are found to contribute up to 75% of deposition near the emission sources. Mercury emissions from the electricity generation sector contributed half the deposition in the Northeast, Southeast, and East Central regions, whereas emissions from natural processes were more important in the Pacific and West Central regions (contributing up to 40% of deposition), suggesting that the implementation of the new EPA MACT standards will significantly benefit only the first three regions.

Pan et al. (2006, 2007, 2008) have previously examined the fate and transport of Hg and its associated uncertainties in the East Asia region using the Hg extension of the Sulfur

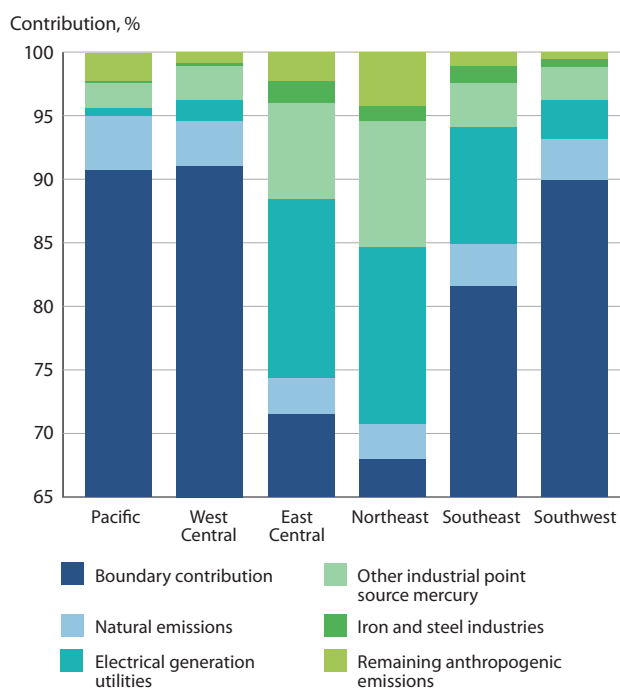


Figure 3.18 Source contribution to annual mercury deposition by the source sectors in six sub-regions of the United States. Source: adapted from Lin et al. (2012).

Transport Eulerian Model (STEM-Hg). More recently, Pan et al. (2010; STEM-Hg) and Lin et al. (2010; CMAQ-Hg), in separate studies, conducted comprehensive assessments of Hg budgets within East Asia and examined outflow from the region. Pan et al. (2010) showed strong seasonal variation in Hg concentration and deposition, with contributions from large point sources. They showed that simulations with different oxidation rates reported for the GEM–O₃ reaction (i.e., by Hall, 1995 vs. by Pal and Ariya, 2004) led to a 9% difference in the modelled mean concentration and a 40% difference in the modelled mean deposition. Pan et al. (2010) estimated annual dry and wet deposition for East Asia in 2001 to be within the range 590–735 t and 482–696 t, respectively, whereas Lin et al. (2010) estimated dry deposition of 425 t and wet deposition of 396 t in 2005. The outflow of Hg caused by East Asian anthropogenic emissions was estimated to be 681–714 t/y by Pan et al. (2010) and in the range 1369–1671 t/y (of which 50–60% was from natural sources) by Lin et al. (2010). Figure 3.19 shows average GEM air concentrations and accumulated dry and wet deposition for July in 2005 over East Asia simulated by CMAQ-Hg. Lin et al. (2010) showed that anthropogenic emissions were responsible for most of the deposition (75%) in East Asia and estimated a net removal of GOM (7–15 t/month) and PBM_{2.5} (13–21 t/month) in the domain, and a net export of GEM (60–130 t/month) from the domain.

3.7.4 Investigation of the uncertainties in process parameterisations

One of the greatest model uncertainties comes from the chemical mechanism implemented in Hg models. The Hg chemistry parameterisations employed in models are based on limited laboratory studies and there are still questions over which are the key oxidation reactions (Gårdfeldt and Jonsson, 2003; Calvert and Lindberg, 2005). There are uncertainties associated with the kinetic mechanism, the rate constants, and the nature of the products; this is particularly true for the gas phase oxidation of GEM. Understanding the product distribution between the gas and aerosol phases (i.e., GOM vs. PBM_{2.5}) is important, because the deposition velocity and removal mechanism vary greatly for the different Hg species.

The CMAQ-Hg regional model has been used to investigate the impact of different gas phase oxidation reaction mechanisms on the simulated monthly wet deposition over the United States (see Figure 3.20). The meteorology and Hg emission inventory employed in each of the simulations were identical. The first plot (Case 1) shows the model result using GEM oxidation by OH (8.7×10^{-20} cm³/molec/s) and O₃ (3.0×10^{-20} cm³/molec/s), this is the scheme implemented in most models. The other subplots show the results obtained when there is no oxidation by OH (Case 2), no oxidation by O₃ (Case 3), no oxidation by either OH or O₃ (Case 4), using a higher kinetic constant for the O₃ oxidation pathway (7.5×10^{-19} cm³/molec/s) (Case

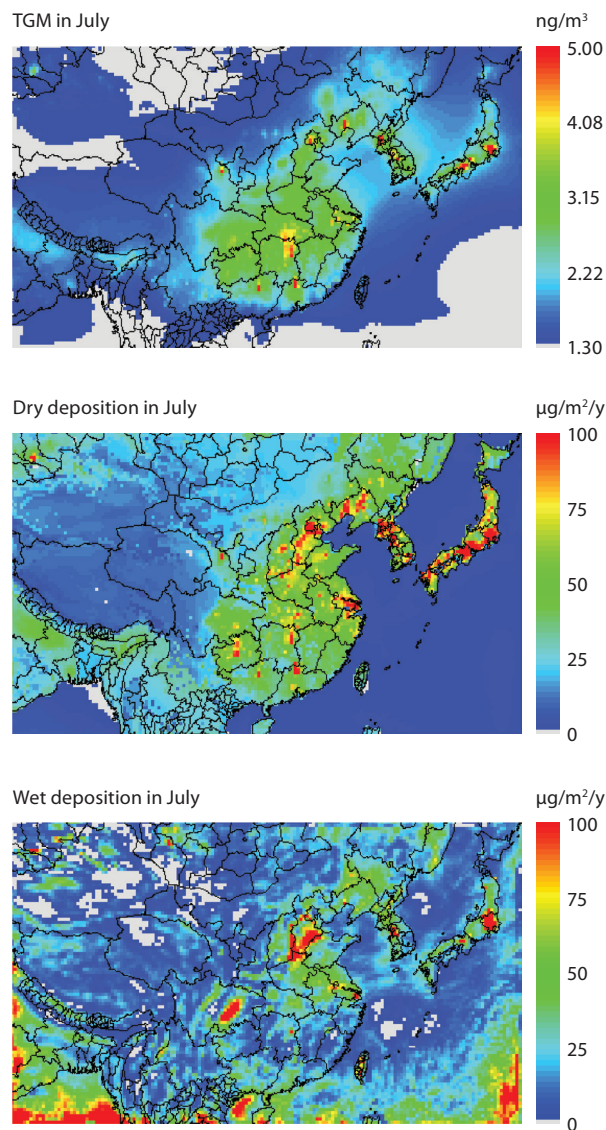


Figure 3.19 Spatial distribution of the monthly average surface air concentrations of total mercury (GEM + GOM+ PBM_{2.5}) (a), and monthly cumulative dry deposition (b) and cumulative wet deposition (c) normalised to annual deposition (µg/m²/y). Source: adapted from Lin et al. (2010).

5), assuming that there is no HgII reduction by aqueous HO₂ (Case 6), and finally no reduction by aqueous HO₂ and no gas phase oxidation by OH (Case 7). As seen in Figure 3.20, removing the OH oxidation mechanism results in a more significant decrease in wet deposition (Case 2) than when the O₃ oxidation mechanism is removed (Case 3), indicating that OH is the dominant oxidant of GEM in the model. Removing both oxidation reactions illustrates the Hg wet deposition which is the direct result of anthropogenic emissions (Case 4). Implementing the higher rate constant for the GEM–O₃ reaction causes much greater wet deposition (Case 5). Removing the aqueous reduction of HgII by HO₂ results in unreasonably high wet deposition (Case 6), and also causes rapid Hg depletion in the gas phase. Case 7 shows that reduction of HgII by HO₂ proceeds more rapidly in the model than GEM oxidation by OH. The magnitude of uncertainty in total wet deposition in the modelling

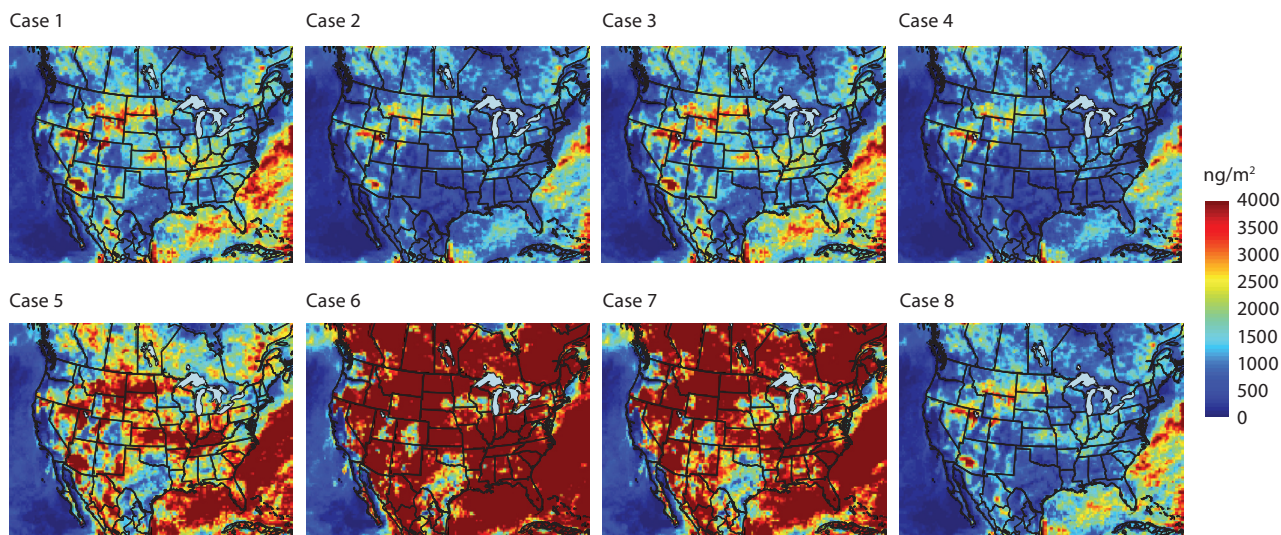


Figure 3.20 Impact of mercury chemistry uncertainty on the simulated monthly mercury wet deposition for the United States in July 2001. The graphic shows eight simulations - see the main text for details. Source: adapted from Travníkov et al. (2010) (cited in: Pirrone and Keating, 2010).

domain, (using Case 1 as the reference simulation) ranges from -50% to +300%. Atmospheric oxidation of GEM is the most important factor determining Hg deposition fluxes in regions far from anthropogenic sources. Improved experimental data addressing these kinetic and product uncertainties would greatly improve model performance in simulating both dry and wet deposition.

3.7.5 Development of process parameterisations

Emissions of GEM from natural processes (re-emission of legacy Hg or primary geogenic emissions) are estimated to be similar to or greater than current anthropogenic emissions, hence their importance to atmospheric Hg models. Traditionally, Hg models have parameterised deposition and surface evasion as independent processes. However, dynamic coupling of Hg exchange at terrestrial and aquatic surfaces is needed to assess the possible impact of changes in anthropogenic emissions or environmental factors such as climate change on the global Hg cycle. Bash (2010) developed and tested a parameterisation for the bi-directional exchange of Hg for the CMAQ (Community Multiscale Air Quality) model that depends on the Hg concentrations in air and surface media. The GEM air-surface exchange was modelled as a function of a dynamic compensation point, which depends on the sources and sinks of GEM in vegetation and soil. This author found that for July, using dynamic bi-directional Hg exchange resulted in an estimated 8.5% of total Hg deposited to terrestrial systems and 47.8% of total Hg deposited to aquatic systems being re-emitted as GEM. Simulations without dynamic bi-directional Hg exchange gave corresponding values of 70.4% and 52.5%. The evasion rates from bi-directional surface Hg exchange were in better agreement with recent estimates of Hg cycling using stable isotopic mass balance experiments.

Simultaneous evaluation of three main atmospheric Hg species: GEM, GOM, and $\text{PBM}_{2.5}$, has been limited by lack of ambient measurement data. Holloway et al. (2012) evaluated GEM, GOM, and $\text{PBM}_{2.5}$ simulated by CMAQ-Hg, in the Great Lakes Region, at both a rural and urban site. Ambient Hg exhibited significant biases at both sites. They found GEM to be too low in CMAQ-Hg, with the model showing a 6% low bias at the rural site and a 36% low bias at the urban site; whereas oxidised Hg (GOM, $\text{PBM}_{2.5}$) was over-predicted by the model, with annual average biases of over 250%. Sensitivity simulations to isolate background inflow from regional emissions suggested that oxidation of imported GEM dominates model estimates of GOM at the rural study site (91%), and contributes 55% to the GOM at the urban site. Their analysis suggested that GEM oxidation rates may be too high in the model, and that the emission ratio of GOM to GEM in urban areas may be inaccurate. These uncertainties in the model have significant implications for estimates of the importance of boundary inflow and regional contributions to local deposition. The authors concluded that Hg chemistry mechanisms and speciation need to be better constrained in order to utilise the model for Hg source attribution studies.

3.8 Conclusions

3.8.1 New findings on atmospheric pathways, transport and fate

It is clear that over the past few decades, and particularly in recent years, much progress has been made in the effort to better understand the sources, chemistry, transport, and deposition of atmospheric Hg. Research studies around the world have provided a better understanding of the relative importance of natural and anthropogenic emission sources,

and have expanded the spatial and temporal coverage of atmospheric Hg measurements, which has supported the development and validation of both regional and global atmospheric Hg models. The ever increasing amount of atmospheric and deposition data available is providing more constraints on the rates of processes involved in the atmospheric Hg cycle. Advances in modelling are beginning to permit the linking of atmospheric, ocean and terrestrial models and to tentatively suggest relationships between atmospheric deposition and ecosystem/human exposure to MeHg. It is however very early days from this point of view.

A major accomplishment in the past two years has been the initial development of a concerted international effort to monitor the concentrations and speciation of atmospheric Hg through the GMOS project. The continued efforts of this programme in close cooperation with existing national and regional monitoring programmes will increase the extent of atmospheric and deposition measurements at remote global locations, particularly in the southern hemisphere. The improved spatial and temporal coverage of Hg measurements, following existing standard operating procedures, will provide the data and information for model validation, and for accurate future predictions of the impact of changing Hg emissions on terrestrial and aquatic ecosystems. The continued development and expansion of ground-based measurements is needed in order to more clearly detect changes in atmospheric Hg concentration over time and across the globe. This effort must be approached from a global perspective with collaboration and participation of existing monitoring programmes and networks so as to benefit from existing techniques and collectively improve the approaches to quantifying atmospheric Hg. In reality, the current spatial measurements coverage is insufficient to detect spatial and temporal trends in atmospheric Hg concentration, or to validate regional and global-scale Hg models; however, with the ongoing global-scale measurement expansion, this situation is expected to greatly improve and it will become possible to address these important scientific and policy questions.

3.8.2 Research gaps and areas for future studies

An important attempt is underway through the development of GMOS to develop a globally coordinated monitoring plan which is aimed to fill gaps in terms of monitoring capability in the southern hemisphere, and to establish close cooperation with existing regional and national monitoring networks and programmes. In addition to routine, long-term monitoring campaigns, there is also a need to support coordinated studies of Hg in the upper troposphere through high-altitude and aircraft measurements so as to better understand the vertical distribution of Hg species in the troposphere, as well as long-range Hg transport and source-receptor relationships. An improved understanding of the vertical distribution of atmospheric Hg species is needed for validating regional

and global-scale models. New measurement and modelling studies that examine key physical and chemical processes related to global transport and Hg cycling are also needed. This could involve process-based measurements, new monitoring or analytical techniques, and model simulations that examine different chemical scenarios. Continued model development and execution of advanced process-based field experiments can be used to ensure that the models are correctly parameterised. These types of study would also allow improved agreement between models and between model output and experimental data.

More specifically, there are a number of chemical and physical processes that are not well understood, but if they could be investigated more thoroughly it would become possible to improve the chemistry and other parameters in existing Hg models. For example, the chemical form of GOM is not fully understood. Understanding the chemical composition of oxidised Hg compounds is critical to improving model chemistry. Similarly, the redox reaction rates and temperature-dependent rate constants for Hg with atmospheric oxidants also need to be better understood to improve model performance.

Finally, whole-ecosystem studies of Hg are needed to better understand Hg biogeochemical cycling. The link between atmospheric Hg deposition, its methylation, and its eventual uptake by living organisms is also an important area for further investigation. A better knowledge of processes that affect the exchange of gaseous Hg species at ecosystems' interfaces (air-water / -soil / -vegetation) would allow a better parameterisation of these processes in Hg cycling models leading to a better qualified uncertainty estimate of exchanged Hg fluxes.

To summarise:

- There is a need to coordinate activities at the global level to ensure that future research provides the maximum benefits in terms of assessing global and regional trends in Hg concentration in different environmental compartments, including biota.
- The current level of measurements and evaluation is inadequate for determining the extent of temporal and spatial changes in atmospheric Hg concentrations. There is a need to coordinate activities at the global level, including leveraging existing regional networks where investments have already been made.
- There is a need for a permanent global monitoring network (such as that which could be built through the GMOS initiative) to ensure that relevant information is obtained that can also be used for model testing and evaluation.
- In terms of long-range transport and source-receptor relationships, there is a need to facilitate coordinated upper tropospheric studies to better understand the vertical distribution of Hg species in the troposphere. This information is needed to help validate regional and global scale models and reduce the uncertainty in their predictive capabilities for different policy scenarios.

- More investigation, using measurements and models, is required for different key processes related to global transport and cycling of Hg. Model development and focused process studies must continue to be expanded and enhanced to ensure that the models are correctly parameterised and that there is agreement between individual models and between model output and experimental data. Without accredited models, it is difficult to make the pertinent forecasts and scenario predictions that are crucial to the development of sound management strategies for the control and mitigation of the current global Hg problem.
- The chemical form of GOM is not actually known. It is operationally defined as oxidised Hg compounds, but what those compounds are is not well understood.
- Redox reaction rates for Hg with atmospheric oxidants need further investigation. There is still no consensus on which oxidants are important, although recent studies suggest that Br (and possibly Br-containing compounds) are a large contributor. More work is needed to understand the relative importance of these redox reactions as well as to determine temperature-dependent rate constants.
- The link between atmospheric Hg deposition, its methylation, and its eventual uptake by living organisms is an important area for further investigation.
- The parameters which determine the rates of exchange of Hg compounds at air-sea, air-soil, and air-vegetation are not fully understood, but an improved understanding of these parameters is needed in order to improve existing Hg models.

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Lead and co-authors of the sections of Chapter 3 are as follows:

3.1 Introduction (*N. Pirrone*); 3.2 Atmospheric chemistry (*I. Hedgecock*); 3.3 Monitoring networks and programmes around the world (*Leads: F. Sprovieri, L. Gratz; Co-authors: X. Feng, N. Pirrone, E. Prestbo*); 3.4 Atmospheric mercury measurements and trends worldwide (*Leads: L. Gratz, F. Sprovieri; Co-authors: R. Ebinghaus, X. Feng*); 3.5 High altitude mercury measurements (*Lead: R. Ebinghaus, Co-authors: L. Gratz, D. Jaffe, F. Sprovieri*); 3.6 Global mercury modelling (*Lead: O. Tranikov; Co-author: I. Hedgecock*); 3.7 Regional mercury modelling (*Lead: A. Dastoor; Co-author: I. Hedgecock*); 3.8 Conclusions (*Lead: Nicola Pirrone; Co-authors: L. Gratz, I. Hedgecock, S. Cinnirella, F. Sprovieri*).

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4. Global Releases of Mercury to Aquatic Environments

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4.1 Introduction

Most previous global mercury inventories have only addressed Hg emissions to the atmosphere; releases to aquatic environments have been largely neglected. The results presented here thus represent a first attempt at producing an inventory of Hg releases to aquatic environments on a global scale, taking into account Hg released from anthropogenic and natural sources, as well as sources associated with previously accumulated Hg remobilised from terrestrial to aquatic systems.

The main focus of this chapter is on Hg released to aquatic systems from anthropogenic sources. Natural sources are also considered in order to establish the relative contribution of the anthropogenic component. In the inventory estimates presented here, it is important to distinguish the **direct current releases** of Hg to aquatic systems (i.e., Hg discharged directly into water bodies such as oceans, rivers and lakes) from the more general **inputs** of Hg to water bodies via other pathways, such as atmospheric deposition of Hg to ocean surfaces, or to soils that are subsequently washed into river systems, or riverine inputs of Hg to oceans. One reason for distinguishing between the two categories of input is to avoid double counting current anthropogenic releases.

Two types of anthropogenic sources are considered here: (i) point sources where anthropogenic activities discharge Hg-containing wastes (intentionally or unintentionally) directly to water bodies, and (ii) diffuse releases of Hg through its remobilisation from contaminated surfaces surrounding sites where Hg was used or was/is present in a range of products and processes.

For some sources of Hg to aquatic ecosystems, a lack of detailed information prevents reliable quantitative estimates of Hg release and these sources can only be addressed qualitatively. These sources include land management practices such as deforestation and agriculture, offshore activities, and the use and consequent release of Hg in artisanal and small-scale gold mining (ASGM).

In contrast to Chapter 2 (which deals with atmospheric emissions), the numbers presented here do not necessarily correspond to the year 2010. For example, the underlying assumptions for estimating Hg releases from diffuse sources are based on average annual long-term hydro-meteorological conditions, while releases from point sources were derived from atmospheric inventory data for 2010 presented in Chapter 2, using the UNEP Toolkit distribution factors approach.

Knowledge of Hg releases to aquatic environments is extremely important because it is within aquatic environments that inorganic forms of Hg are converted into the more toxic and bioavailable methylmercury (MeHg) form, thus making the Hg available for accumulation and biomagnification within aquatic food webs. Transport of Hg from its source to aquatic environments depends greatly on its chemical form since it is this in combination with site-specific environmental conditions that determines its mobility, reactivity and bioavailability. Such issues are addressed in more detail in Chapter 5. The main focus of the present chapter is a global inventory and quantification of Hg releases to aquatic systems from sources for which sufficient information is available.

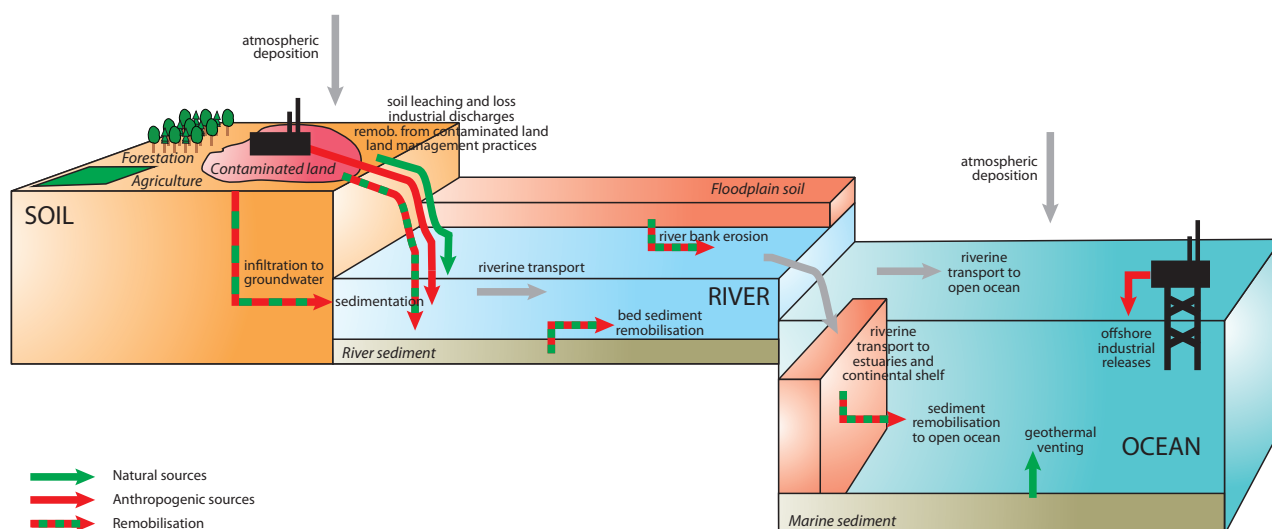


Figure 4.1. Schematic illustration of the major pathways and sources of mercury to aquatic environments.

4.2 Transport pathways for mercury released to aquatic environments

Releases of Hg to aquatic environments can be more complex and difficult to trace in terms of transport routes and source allocation than atmospheric Hg emissions. Figure 4.1 illustrates the major source components and pathways that introduce Hg to aquatic systems.

One of the most important pathways for introducing Hg to aquatic systems is atmospheric deposition. While Hg deposited onto rivers, lakes and oceans enters these systems directly, Hg deposited on land is only partly transported to local aquatic systems (via surface runoff) since a considerable proportion is retained by vegetation and soil. Due to enhanced atmospheric deposition as a result of human activities, the global soil Hg burden has increased considerably since pre-industrial times. Soils can also be significantly enriched in Hg through local releases from industrial installations (see Section 4.3.2.2). This terrestrial Hg pool then serves as a source of Hg for freshwater systems (rivers, lakes and reservoirs) through soil leaching and erosion, with the Hg in both the dissolved and particulate phase. In rivers, Hg associated with particulates is partly sedimented onto the river bed, with the rest (dissolved phases and Hg associated with suspended sediments) transported to downstream environments. During periods of high water flow, this input is enhanced due to river bank erosion and remobilisation of Hg previously deposited with bed sediments. Rivers are an important transport pathway since they convey Hg from one point to another. Ultimately, rivers carry Hg to the marine environment. There, only a small proportion of the total riverine load directly reaches the open ocean, as the majority is deposited in estuaries and on the continental shelf (from where the slow but continuous remobilisation of dissolved and particulate Hg takes place). Exploration and exploitation activities offshore and in coastal waters (such as oil drilling and dredging of bottom sediments etc.) can also contribute Hg directly to the open ocean.

An overall global Hg budget (atmospheric emissions included) based on recent modelling work is discussed in detail in Chapter 1. In order to provide context for the present discussions, a short summary of the global Hg cycle relevant for Hg releases to the aquatic environment is given here based on the most recent data presented by Mason et al. (2012) and references therein. At the global scale, the most recent total atmospheric deposition of Hg (comprising Hg from natural and anthropogenic sources) was estimated at 3200 t/y to land and 3700 t/y to oceans. However, a large proportion of the Hg deposited to both the land and oceans is re-emitted to the atmosphere. Various global models of Hg cycling imply annual (re-)emissions to air from soils and oceans of 1700–2800 t/y and 2000–2950 t/y, respectively. At coastal sites, riverine fluxes can also be important. Estimates of total global river discharges of Hg to estuaries are large (>2800 t/y), but only a small proportion of this Hg is transported to open ocean regions (~380 t/y).

As is the case for Hg emissions to the atmosphere, Hg released to and transported within and between aquatic systems comes from a variety of sources and it is not always possible to determine the origin of the Hg. For the purposes of this study, three types of source are distinguished: new (current) releases from **natural** sources, new (current) releases from **anthropogenic** sources, and **remobilisation** of previously deposited and accumulated Hg (see Figure 4.1).

- Natural sources comprise: (i) Hg released to local aquatic systems from terrestrial surfaces due to its natural (geogenic) occurrence in the earth's crust via leaching, runoff and erosion processes; and (ii) submerged hydrothermal venting. This topic is discussed in Section 4.3.1.
- Anthropogenic sources represent Hg released to aquatic systems as a result of current human activities due to the use and/or presence of Hg in a variety of products and processes (primary and secondary anthropogenic sources are discussed in Chapter 2). These sources comprise: (i) Hg released with the water effluents leaving production sites/plants where Hg is intentionally used (e.g., ASGM, various industrial and chemical processes, production of Hg-containing products, offshore activities); and (ii) leaching from solid waste disposal sites associated with both the unintentional and intentional presence/use of Hg. This topic is discussed in Section 4.3.2.1.
- Remobilisation comprises the release of Hg previously deposited to or accumulated in various environmental compartments by human activities. These are the result of natural processes augmented by anthropogenic activities and include: (i) enhanced atmospheric deposition of Hg as a result of anthropogenic activities (see Chapter 3 for details); (ii) leaching and erosion of Hg-contaminated surfaces; (iii) river bank erosion, and resuspension of river bed sediment and sediment accumulated at coastal sites; and (iv) enhanced Hg releases as a result of various land and water management practices (e.g., agriculture, forestation, dam construction, sediment dredging). These sources can be of local importance only or dispersed over large areas, such as river catchments and contaminated coastal areas. This topic is discussed in Section 4.3.2.2.

4.3 Releases of mercury to aquatic environments

4.3.1 Releases from natural sources

This section discusses inputs of Hg to aquatic systems due to its natural occurrence in terrestrial environments via leaching, runoff and erosion processes; and releases of Hg from undersea hydrothermal vents to open oceans.

Mercury is drained into seas and oceans from the whole continental area, which makes assessment of the relative

contribution from natural sources difficult. For the assessment of Hg fluxes from terrestrial environments to rivers and further to seas and oceans, a good knowledge of the spatial distribution of Hg content in soils and rivers is needed, along with site-specific hydro-meteorological and land cover conditions that drive erosion processes. It has been estimated that the total natural (pre-industrial) global soil Hg burden is of the order of 10^6 t for the top 15 cm of soil and that human activities have enhanced this burden by approximately 15% (Selin, 2009). Similarly, Smith-Downey et al. (2010) found that the pre-industrial content of organically bound Hg in soils was 200 000 t globally and that organic soils have stored ~20% of anthropogenic Hg emissions since 1840.

Here, an attempt was made to reconstruct global inputs of Hg to river systems from natural sources only. Two different approaches were used to estimate the natural component of these releases, using different assumptions, as follows. In the first approach, natural annual fluxes of Hg are assumed to be in the range $1\text{--}3\text{ }\mu\text{g}/\text{m}^2/\text{y}$, as reported in the literature for various remote and pristine environments (see Grigal, 2002). Applying this range over the total area of the Earth's land surface ($\sim 1.5 \times 10^8\text{ km}^2$ including endoreic regions) results in $150\text{--}450\text{ t}$ of annual Hg input to aquatic systems. In the second approach, modelled river sediment fluxes were combined with the Hg content of the surrounding soils, based on the International Satellite Land Surface Climatology (ISLSCP) Initiative II GIS data (Ludwig et al., 2011a). Values of $40 \pm 20\text{ ng/g}$ were chosen for Hg soil/sediment concentrations, which covers the range usually reported for background values. This is clearly an oversimplification, as the actual global spatial distribution of Hg naturally present in soils and streams is much more complex and depends on factors

such as soil organic carbon content, atmospheric deposition etc.; however it serves the purpose for a relative comparison of natural and anthropogenic sources. In this way, values were obtained that were similar in magnitude but somewhat larger than with the first approach: $\sim 320\text{--}960\text{ t}$ (average 640 t) of annual Hg input. The highest natural Hg fluxes to local aquatic systems occur at sites with high erosion rates and consequently higher sediment yield: mountainous regions with steep slopes and a humid climate that enhance erosion processes. In these areas, fluxes can exceed tens or even hundreds of $\text{g Hg}/\text{km}^2$ (Figure 4.2). It should be noted that many of these sites coincide with the global distribution of Hg mineral belts and tectonically active areas where soils can be naturally enriched in Hg, resulting in locally elevated inputs to local streams (e.g., the Mediterranean basin, Southeast Asia, and mountainous areas of the Pacific mineral belt).

Hydrothermal vents are an important natural source of Hg for open oceans, most of them being located along the mid-ocean ridges. Figure 4.2 shows the locations of 355 hydrothermal vents, obtained from the VENTS Program (online at: www.pmel.noaa.gov/vents/index.html). Globally, inputs of Hg from hydrothermal vents are estimated to be $<600\text{ t/y}$ (Lamborg et al., 2006; Mason et al., 2012). These sources can be of paramount importance especially in geotectonically active areas and semi-enclosed basins such as the Mediterranean Sea (Rajar et al., 2007).

4.3.2 Releases from anthropogenic sources

This section addresses Hg releases to aquatic systems as a result of human activities. The first part (Section 4.3.2.1)

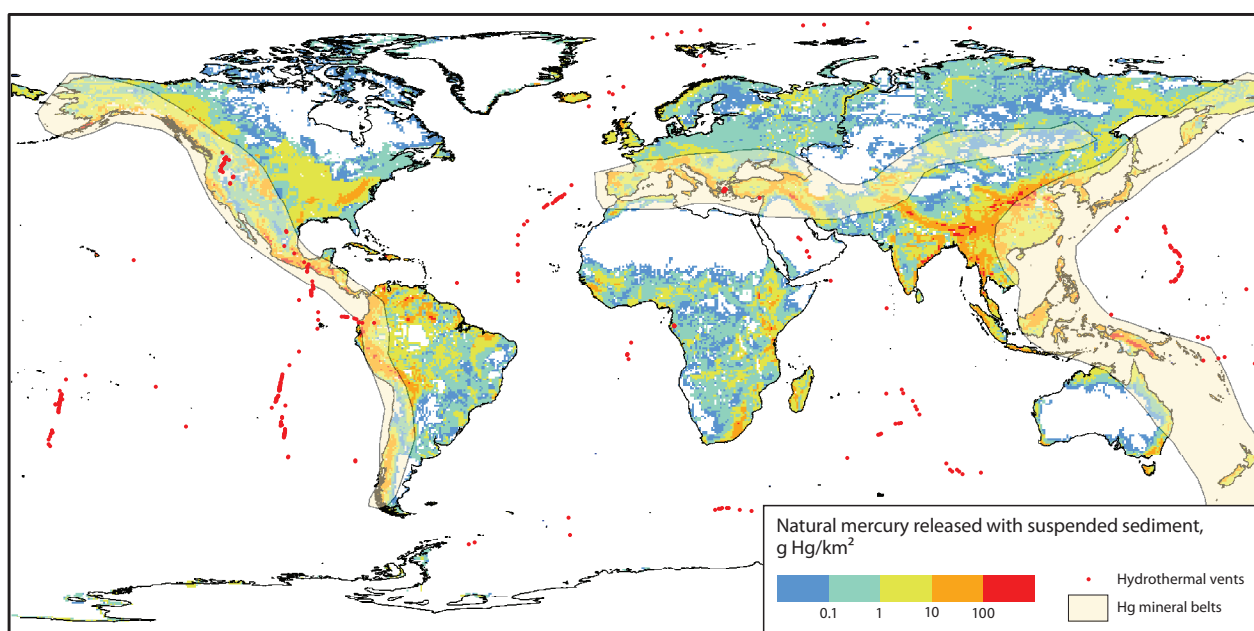


Figure 4.2. Natural mercury fluxes (per 0.5 grid cell) associated with suspended material (based on ISLSCP data (Ludwig et al., 2011a) obtained from: <http://dx.doi.org/10.3334/ORNLDAAAC/1019>) in river systems. The global distribution of mercury mineral belts (modified from Gustin et al., 1999 and Rytuba, 2003) and hydrothermal vents (locations obtained from: www.pmel.noaa.gov/vents/index.html) are also shown.

covers Hg releases from point sources. Due to the differences in approaches used, these sources are discussed separately for the various industrial installations (chlor-alkali industry, oil refining, non-ferrous metals processing), ASGM, and offshore oil and gas operations. In the second part (Section 4.3.2.2) diffuse releases of Hg to aquatic systems are discussed, including riverine inputs to coastal environments, remobilisation from contaminated sites, and releases as a consequence of land and water management practices.

4.3.2.1 Releases of mercury to aquatic systems from point sources

4.3.2.1.1 Releases of mercury from industrial installations

In general, releases of Hg to aquatic environments from anthropogenic point sources are very poorly documented, and unlike the case for air emissions, no recent global inventories of anthropogenic Hg releases to water exist. Some (European) countries report estimates of Hg releases to water under international programmes, such as OSPAR (www.ospar.org) and HELCOM (www.helcom.fi), but this is mainly for the purpose of deriving estimates of inputs (via riverine inputs and direct discharges) to the marine areas covered by these Conventions. Other countries have delivered national estimates

Table 4.1. UNEP Toolkit distribution factors used for calculation of releases from point sources. Source: UNEP (2011a,b).

NFM: non-ferrous metal production; CAP: Chlor-alkali production with Hg-technology.

Source category	Distribution factors		
	Air	Water	Land
Oil refining	0.25	0.01	-
NFM-Cu	0.1	0.02	0.24
NFM-Pb	0.1	0.02	-
NFM-Zn	0.1	0.02	-
NFM-Al	0.15	0.1	-
NFM-Hg	0.25	0.06	0.69
NFM-Au	0.04	0.02	0.9
CAP	0.1	0.01	0.01
Other waste	0.1	0.1	0.8

of Hg releases to water (in different years) to UNEP through national Hg release inventories prepared using the UNEP Toolkit [online at: www.unep.org/hazardoussubstances/Mercury/Informationmaterials/ReleaseInventories/tabid/79332/Default.aspx]. Mercury releases to water from specific industrial

Table 4.2. Calculated annual releases of mercury to aquatic systems by sub-region and for various sectors (data in tonnes).

NFM: non-ferrous metal production; CAP: Chlor-alkali production with Hg-technology; ASGM: Artisanal and small-scale gold mining; EU27: The 27 EU Member States.

Sub-region	Oil refining	NFM-Cu	NFM-Pb	NFM-Zn
Australia, New Zealand & Oceania	0.003 (0.001–0.005)	0.16 (0.06–0.81)	0.03 (0.01–0.05)	0.62 (0.37–0.69)
Central America and the Caribbean	0.004 (0.002–0.006)	0.43 (0.21–1.83)	0.04 (0.02–0.07)	1.08 (0.55–2.25)
CIS & other European countries	0.043 (0.019–0.071)	2.77 (0.99–13.9)	0.07 (0.02–0.15)	1.94 (0.74–4.44)
East and Southeast Asia	0.381 (0.172–0.629)	6.45 (2.38–31.8)	0.69 (0.24–1.42)	9.29 (5.21–14.9)
EU27	0.081 (0.039–0.134)	1.11 (0.40–5.58)	0.05 (0.02–0.10)	1.13 (0.46–2.56)
Middle Eastern States	0.007 (0.003–0.011)	0.53 (0.19–2.66)	0.01 (0.002–0.01)	0.14 (0.05–0.33)
North Africa	0.007 (0.003–0.012)	–	0.02 (0.01–0.05)	0.11 (0.04–0.27)
North America	0.072 (0.034–0.119)	0.24 (0.09–1.17)	0.01 (0.003–0.01)	0.07 (0.04–0.58)
South America	0.012 (0.005–0.020)	3.72 (1.33–18.6)	0.01 (0.004–0.02)	0.95 (0.36–2.30)
South Asia	0.028 (0.013–0.046)	2.24 (0.80–11.2)	0.03 (0.01–0.07)	2.16 (0.81–5.31)
Sub-Saharan Africa	0.001 (0.001–0.002)	1.11 (0.40–5.57)	–	0.50 (0.19–1.24)
Total	0.639 (0.293–1.055)	18.8 (6.83–96.16)	0.95 (0.35–1.97)	18.0 (8.83–34.9)

^a Releases to land and water as discussed in Section 4.3.2.1.2.

facilities are also partly included in databases/registers such as North American Pollutant Releases and Transfers (NAPRT, comprising Canada's National Pollutant Release Inventory [NPRI], Mexico's Registro de Emisiones y Transferencia de Contaminantes [RETC], and the United States' Toxics Release Inventory [TRI], online at: www.cec.org); the European Pollutant Release and Transfer Register (E-PRTR, covers the 27 EU Member States as well as Iceland, Liechtenstein, Norway, Serbia and Switzerland, online at: <http://prtr.ec.europa.eu/>); and the Australian National Pollution Inventory (NPRI, online at: www.npi.gov.au). On a sector basis, efforts have been made to compile information on releases from specific activities. For example, OSPAR reporting also includes annual reporting (most recently for 2009) of releases of Hg from the chlor-alkali industry (OSPAR, 2011).

The approaches and underlying assumptions used in the preparation of these inventories and release estimates differ from country to country and different databases/registers cover different industry sectors and economic activities, which makes comparison of various inventories difficult. Moreover, reporting requirements are subject to different thresholds and often lack documentation and transparency/traceability with regard to the basis for the estimates (see discussion in Chapter 2), although the UNEP Toolkit approach (UNEP, 2011a,b) attempts to address these issues.

In the absence of detailed information necessary to prepare a comprehensive inventory of releases to water, and in order to produce a first-order global inventory of anthropogenic Hg releases to water, a crude approach combining the atmospheric inventory results presented in Chapter 2 of this report with the information and assumptions included in the UNEP Toolkit approach has been employed. This approach adopts the (default) distribution factors that are applied in the UNEP Toolkit to 'distribute' total Hg releases to the environment between air, water and land (Table 4.1), and uses these factors to calculate corresponding releases to water for the air emissions developed in Chapter 2 of this report. It should be recognised that this is a very coarse approach, with large associated uncertainties. Namely, the uncertainties related to atmospheric emission estimates associated with the activity data used, emission factors and assumptions made regarding applied technologies (see Chapter 2 for details) are compounded by additional uncertainties related to the validity and utility of the Toolkit distribution factors. It should also be noted that this approach has the potential to miss releases to water that are associated with activities where air emissions are insignificant (and thus there are no corresponding emissions included in the air emissions inventory).

Using the approach described above, anthropogenic releases to water have been calculated, and the results by sub-regions for various sectors are given in Table 4.2. These

NFM-AI	NFM-Hg	NFM-Au	CAP	Other waste	ASGM ^a
0.21 (0.08–0.44)	–	6.31 (0.04–16.4)	–	0.47 (0.13–1.60)	3.50
–	–	1.95 (0.02–4.48)	0.06 (0.02–0.12)	3.40 (0.88–11.2)	6.45
0.94 (0.37–1.95)	0.53 (0.31–0.81)	8.04 (0.06–20.9)	1.12 (0.39–2.17)	7.00 (1.81–23.9)	10.3
1.30 (0.52–2.45)	2.27 (1.32–3.44)	11.5 (0.08–29.9)	0.12 (0.04–0.24)	34.3 (8.67–118)	454
0.03 (0.01–0.06)	–	0.14 (0.001–0.36)	0.65 (0.23–1.26)	4.48 (0.93–16.2)	–
0.05 (0.02–0.10)	–	0.25 (0.002–0.66)	0.22 (0.08–0.42)	4.44 (1.12–14.8)	–
0.01 (0.003–0.02)	0.02 (0.01–0.02)	0.06 (0.0004–0.16)	0.13 (0.05–0.26)	2.37 (0.62–7.59)	–
0.12 (0.04–0.24)	–	0.82 (0.01–2.13)	0.11 (0.04–0.21)	4.57 (1.10–16.5)	–
0.21 (0.08–0.43)	–	7.66 (0.06–19.6)	0.25 (0.11–0.42)	7.53 (1.96–25.6)	313
0.31 (0.12–0.64)	–	0.08 (0.001–0.20)	0.16 (0.06–0.31)	16.6 (3.94–58.8)	0.37
0.09 (0.06–0.12)	–	11.9 (0.10–28.8)	0.02 (0.01–0.04)	4.18 (1.03–13.9)	93.7
3.27 (1.31–6.45)	2.82 (1.64–4.28)	48.7 (0.36–124)	2.84 (1.02–5.47)	89.4 (22.2–308)	881

results can be compared with release estimates obtained using independent approaches and assumptions. For example, according to the NAPRT database where North American facilities releases are reported, total on-site surface water discharges in 2009 for all industry sectors included in the database is ~5 t/y. This is very similar to ~6 t/y calculated for North America according to the Toolkit approach. However, in this case it should be mentioned that the sectors included in the NAPRT database differ from the sectors included in the present calculations and, for US air emissions at least, NAPRT-based totals are lower than those reported under the US national emission inventory (NEI). Similarly, the OSPAR Commission reported 0.14 t of Hg released with waste water from 29 chlor-alkali plants located within the OSPAR region in 2009 (OSPAR, 2011e). Applying this value to 39 chlor-alkali plants still using Hg cell technologies in the 27 EU Member States (UNEP, 2011) would result in an annual release of 0.18 t from this sector. This is similar in magnitude but somewhat lower than the calculated 0.65 t/y using the Toolkit approach. For the oil refining sector, a wide range of values for Hg releases to water are reported for different regions in various databases/registers: for example, 0.03–0.36 kg/facility in 2011 (NPRI, Australia), 0.2–1.28 kg/facility in 2010 (NPRI, Canada) and 645 kg from 17 mineral oil and gas refineries in Europe in 2010 (E-PRTR). Measurements implemented within the framework of the EU research project BIOMERCURY (Horvat et al., 2007) revealed that in an oil refinery in central Europe the concentration of Hg in purified waste water was 2.1 µg/L, while the concentration in waste water treatment sludge reached over 230 µg/kg. The mass balance indicated that about 16% of Hg entering the oil refinery was discharged by waste waters (Horvat et al., 2007). Considering these ranges and applying a rather conservative value of 0.5 kg/y of Hg released from over 650 oil refineries globally (OGJ, 2006) would approximate to 0.3 t/y, which is similar to the 0.6 t/y using the Toolkit approach.

It should be noted, however, that Hg releases to water might also be significant for some sectors currently not covered by the UNEP Toolkit as no distribution factors exist for these categories that would enable calculation of the releases. For example, out of 9.29 t of Hg released to water from 423 facilities reported in E-PRTR in 2010, 6.79 t is attributed to releases from urban waste-water treatment plants. Considering the large number of these facilities, the large volumes of water used in the process and the fact that the threshold for Hg releases to water in E-PRTR is set at the relatively high 1 kg/y, actual releases might be significantly higher. Sewage treatment can also be an important sector. Based on Canada's NPRI, 0.14 t of Hg was released to water from 23 sewage treatment plants in 2010.

4.3.2.1.2 Releases due to mercury use in ASGM activities

Environmental impacts due to the Hg use in ASGM activities have been documented in many studies, and a comprehensive

review of worldwide ASGM activities was made by Telmer and Veiga (2009). According to most recent estimates, ASGM releases to all environmental compartments averaged 1607 t Hg/y globally (range 910–2305 t/y) in 2011. Of these, on average 55% is released to terrestrial systems, resulting in an input of 881 t/y (range 498–1263 t/y). The ratio between Hg emitted to the atmosphere and that released to terrestrial systems depends on the practices used in ASGM activities. As discussed in Chapter 2 of this report (where methodology used for release estimates is described in more detail), in regions where concentrate amalgamation is practised, 75% of the Hg used is emitted to the atmosphere, whereas localities that practise whole ore amalgamation release a much larger proportion of the Hg to aquatic and terrestrial systems. Based on the knowledge about ASGM practices employed in each country in Table 4.2 these releases are summarised for different sub-regions. The data presented in this table show the total annual amount of Hg released due to its active use in ASGM activities and which accumulates in local rivers, lakes, soils and tailings. However, a proportion of the amount released into these terrestrial ecosystems is later remobilised to the hydrosphere. How much actually enters aquatic environments due to erosion and is further subjected to riverine transport is unknown and hard to establish due to the lack of suitable data. For this purpose, the extent of contamination should be established for each individual site, as well as a good knowledge regarding site-specific hydro-meteorological conditions. However, as ASGM activities are conducted at hundreds of small sites, they cannot be individually identified. Moreover, as these sites are distributed globally in zones with very variable hydro-meteorological conditions, it is reasonable to expect that inputs to local aquatic systems will significantly differ from site to site. Therefore, just to give a rough estimate of the possible global remobilisation of Hg from these sites, a semi-quantitative approach was used. Countries with known ASGM activities were grouped according to their susceptibility to erosion. For this purpose, global composite surface runoff data available in the GIS format were used (Fekete et al., 2000), as runoff is the most important driver of soil erosion. Countries were then classified into three groups: countries with a very dry climate (on average <100 mm surface runoff per year) where aquatic inputs can be considered negligible, countries with a very humid climate (>1000 mm runoff per year) where such inputs can be important, and others that fall in-between these two classes. Using this approach, it was found that most of the countries in the first group are African countries with relatively low production and consequent releases (74 t/y), while many countries in the second group are those with the highest ASGM activity and releases. Among others this includes Colombia, Indonesia, Philippines, Brazil, Guyana, Vietnam, Papua New Guinea, French Guiana, Suriname and Malaysia. Altogether, these countries alone contribute more than 36% (~320 t/y) of global releases to terrestrial compartments from ASGM. Therefore, ASGM

can be a very important source of Hg for aquatic systems. However, it should be mentioned that the dominant source of contamination of local aquatic systems is not necessarily the loss of Hg in the gold amalgamation process itself, but the disturbance and mobilisation of large quantities of Hg-rich sediment and floodplain soil during mining operations (sluicing and dredging), as reported for the Tapajos River in the Brazilian Amazon by Telmer et al. (2006).

4.3.2.1.3 Releases associated with offshore oil and gas operations

Globally, most of the offshore oil and gas fields are located in the Persian Gulf/Middle East, North Sea, West Africa, the Gulf of Mexico (US and Mexico), Asia/Australasia, Brazil, China, the Caspian Sea and Russia/Arctic. Offshore production involves 17 000 operating platforms, with more than 400 new production facilities (fixed, floating and subsea platforms) being constructed every year (IFP Energies nouvelles, 2012). During extraction, Hg associated with crude oil and natural gas is released in wastewater streams and in solid waste streams (IKIMP, 2012). These releases vary a lot from site to site and depend on the Hg content in crude oil and gas, and the technology used at individual sites. Sediments adjacent to offshore drilling sites often contain elevated Hg levels due to its association with barite, a common additive to drilling mud (Wilhelm, 2001; Trefry et al., 2002, 2007). Reported Hg concentrations in drilling muds range from 0.05–0.75 mg/kg (Neff et al., 2003; Trefry et al., 2007; IKIMP, 2012 and references therein). Neff et al. (2003) estimated that 153 kg of Hg was discharged to the Gulf of Mexico in 2001 in permitted discharges of drilling muds and cuttings from a total of 900 wells drilled, while the annual release to North Sea sediments in 2010 was estimated at 12–22 kg (IKIMP, 2012). Applying these values to the global number of wells drilled would result in several tonnes of Hg released to the ocean floor due to this activity. However, such a worldwide extrapolation is associated with large uncertainty. For example, in Norway barite was replaced by ilmenite in 2003, resulting in significantly lower Hg releases (<10 kg annually) from drilling operations on the Norwegian Continental Shelf (NCPA, 2011). Moreover, it should be noted that Hg present in drilling muds and cuttings is present primarily as insoluble sulphide, and MeHg concentrations in sediments and marine organisms around drilling sites were found to be comparable with background sites (Neff et al., 2003; Trefry et al., 2007). Another possible release of Hg to local aquatic systems occurs during the production phase when hydrocarbons, natural gas and water phases are separated, especially as most of the produced water originating on offshore platforms is discharged to the ocean (Wilhelm, 2001). Available information on the Hg content of produced water is relatively scarce and there is a wide range of reported values. In the past there was a lot uncertainty associated with these values due to the poorly developed analytical methods with high detection limits (Wilhelm,

2001), resulting in large variations in reported releases. For example, while Wilhelm (2001) reported 0.3 trillion litres of offshore produced water annually discharged within U.S. oil and gas production and uses 1 µg/L for the Hg concentration, which would result in 300 kg/y of Hg discharged, Neff et al. (2003) reported that produced water usually contains less than 0.1 µg/L and that only 3.6 kg/y of Hg is discharged to the U.S. Gulf of Mexico. More recent data from measurements at just over 100 facilities on the UK Continental Shelf revealed mean Hg concentrations of 0.46 µg/L (2008) and 0.94 µg/L (2009), resulting in annual Hg discharges of 91 and 186 kg, respectively (IKIMP, 2012). Similarly, on the Norwegian continental shelf, ~5–17 kg of Hg was discharged annually with produced water in the 2000–2009 period (NCPA, 2011). On the other hand, significantly higher Hg concentrations in the 30–800 µg/L range are reported for offshore platforms in the Gulf of Thailand with associated Hg releases of between 40 and 330 kg/y in the 1991–1996 period (Chongprasith et al., 2001). Taking into account the number of operating platforms globally and the reported releases of Hg, it can be concluded that oil and gas offshore operations are an important source of Hg for oceans. However, due to the lack of data and large variations in reported concentrations, any global quantification of Hg releases from this sector would be associated with too large an uncertainty.

4.3.2.2 Diffuse releases of mercury to aquatic systems

4.3.2.2.1 Riverine inputs to coastal environments

Part of the Hg being drained into local river systems from sources in the catchments is retained in rivers, mostly associated with the bed sediment, while the rest ultimately reaches coastal sites in both the dissolved and particulate phase. The total Hg load entering lakes and oceans depends on the size of the drainage area and the Hg levels in the basin, and can be quite significant also in non-contaminated basins. For example, Carrie et al. (2012) calculated that 4.3 t of Hg is exported each year to the delta from the Mackenzie River Basin, which is the least human-impacted large watershed in the world, and the Hg input is primarily derived from the weathering of sulphide minerals. The OSPAR Commission reported that 306 t of Hg were discharged into the North-East Atlantic area covered by the OSPAR Convention in the period 1990–2002. Of that, 23 t are direct releases to the sea (for example, through pipelines), while the remaining 283 t are contributed by riverine inputs (OSPAR, 2005). Similarly, recent model results revealed that circumpolar rivers and coastal erosion might be the dominant source of Hg (95 t/y) to the Arctic Ocean (Fisher et al., 2012). Almost 500 kg of Hg has been transported to the New York/New Jersey Harbour from various sources in one year, with 67% of the total input from rivers (Balcom et al., 2008). A Hg mass balance was also calculated for the Mediterranean Sea, which is a relatively closed basin where riverine Hg inputs can be extremely

important. The total mass of Hg in the water column of the Mediterranean Sea for 2005 was estimated at 1080 t, with the contribution of Hg from rivers ~14 t/y and point sources ~2.5 t/y (Rajar et al., 2007). The importance of riverine inputs of Hg to oceans was also emphasised in a recent study by Soerensen et al. (2012) where it was hypothesised that the historical decline of Hg in the North Atlantic Ocean could be attributed to decreased riverine and wastewater inputs at ocean margins.

In addition to terrestrial surfaces being drained to seas and oceans, significant parts of the world's continents belong to so-called endoreic regions. These are regions where rivers flow into internal basins (i.e., without outflow) because of a combination of climatic aridity and continental morphology, and cover 10% of the surface of the continents (Feller, 2010). Some of the most important such regions are Lake Eyre in Australia, the Okavango river system in Africa, the Tarim basin in China, the Great Basin in the United States, Altiplano in South America and the Aral Sea and Caspian Sea drainage in central Asia (Feller, 2010). Significant amounts of Hg can end up in these lakes. One such well known and well studied example is Hg contamination in the Laurentian Great Lakes region in North America, where contamination represents a combination of historical loadings from industrial activities in the drainage area of the lakes as well as enhanced atmospheric deposition in the area (Marvin et al., 2004; Wiener et al., 2012). Lakes with Hg point sources in the drainage area can also be significantly affected. One such example is Clear Lake in the USA, where ~100 t of Hg was deposited into the lake's ecosystem from the Sulfur Bank mercury mine (Suchanek et al., 2008). Sediments trapped in such closed systems act as a sink for Hg from which it can be remobilised by resuspension and represent important sites for the production of MeHg (Ullrich et al., 2001) that affects fish and wildlife.

An approach similar to that of Sunderland and Mason (2007) was used for estimating global Hg inputs to oceans from rivers in both the particulate and dissolved phases. Calculations are based on the long-term average sediment loads and freshwater discharges obtained from ISLSCP Initiative II data (Amiotte-Suchet and Probst, 1995; Ludwig et al., 1996; Hall et al., 2006), available in GIS format (Ludwig et al., 2011b). In this database, sediment yields were predicted by correlating them with the products of hydroclimatic, geomorphological, and lithological factors, while drainage intensity was obtained from Korzoun et al. (1977) and Ludwig and Probst (1998). River Hg concentrations for different ocean basins were adopted from Sunderland and Mason (2007) and references therein. As seen in Table 4.3, the average total annual input of Hg to the coastal sites is estimated at 2473 t. Of that, the majority (95%) is attributed to Hg associated with suspended sediments, the rest being in the dissolved phase. These total inputs are large and in agreement with the numbers reported by Sunderland and Mason (2007), but only a small proportion of (~10%) this Hg is transported to open ocean regions (Mason et al., 2012), the rest being deposited around river mouths and on continental shelves (Cossa et al., 1997; Sunderland and Mason, 2007). Mercury fluxes to the oceans are highest around the mouths of major world rivers and at sites where sediment export is increased due to site-specific hydro-meteorological conditions (Figure 4.3). Many of these sites are located in tropical and subtropical coastal environments which are especially sensitive to Hg loads (Costa et al., 2012).

4.3.2.2.2 Remobilisation of mercury to aquatic environments from contaminated sites

This section discusses remobilisation of Hg from various contaminated terrestrial environments to local aquatic systems. Here, a contaminated site is defined as a site with elevated Hg content relative to local background, as a consequence of Hg use or its presence in a variety of products

Table 4.3. Global particulate and dissolved river mercury inputs to estuaries.

Hg_p: mercury in the particulate phase; *Hg_d*: mercury in the dissolved phase.

Ocean basin	Area ^a , 10 ³ km ²	Sediment ^a , Gt/y	Runoff ^a , km ³ /y	Hg _p ^b , ng/g	Hg _d ^b , ng/L	Hg _p load, t	Hg _d load, t
Arctic Ocean	16982	0.235	3239	80 ± 40	0.6 ± 0.4	9.40 – 28.2	0.65 – 3.25
North Atlantic	27300	3.600	13484	200 ± 100	3.0 ± 2.0	360 – 1080	13.5 – 67.6
South Atlantic	16959	0.523	5074	200 ± 100	3.0 ± 2.0	52.3 – 157	5.09 – 25.4
Pacific	21025	7.407	13532	120 ± 60	3.0 ± 2.0	444 – 1333	13.5 – 67.9
Indian Ocean	16594	3.556	5166	120 ± 60	3.0 ± 2.0	213 – 640	5.18 – 25.9
Mediterranean Sea	6739	0.708	1087	280 ± 140	0.9 ± 0.6	99.1 – 297	0.28 – 1.68
South of 60° S	728	0.007	162	80 ± 40	0.6 ± 0.4	0.28 – 0.84	0.03 – 0.16
Range						1179 – 3537	38 – 192
Average						2358	115
Sum						2473	

^a Area of global land surfaces without endoreic regions and regions that are under permanent ice cover, sediment and runoff data obtained from ISLSCP; ^b river Hg concentrations from Sunderland and Mason (2007) and references therein.

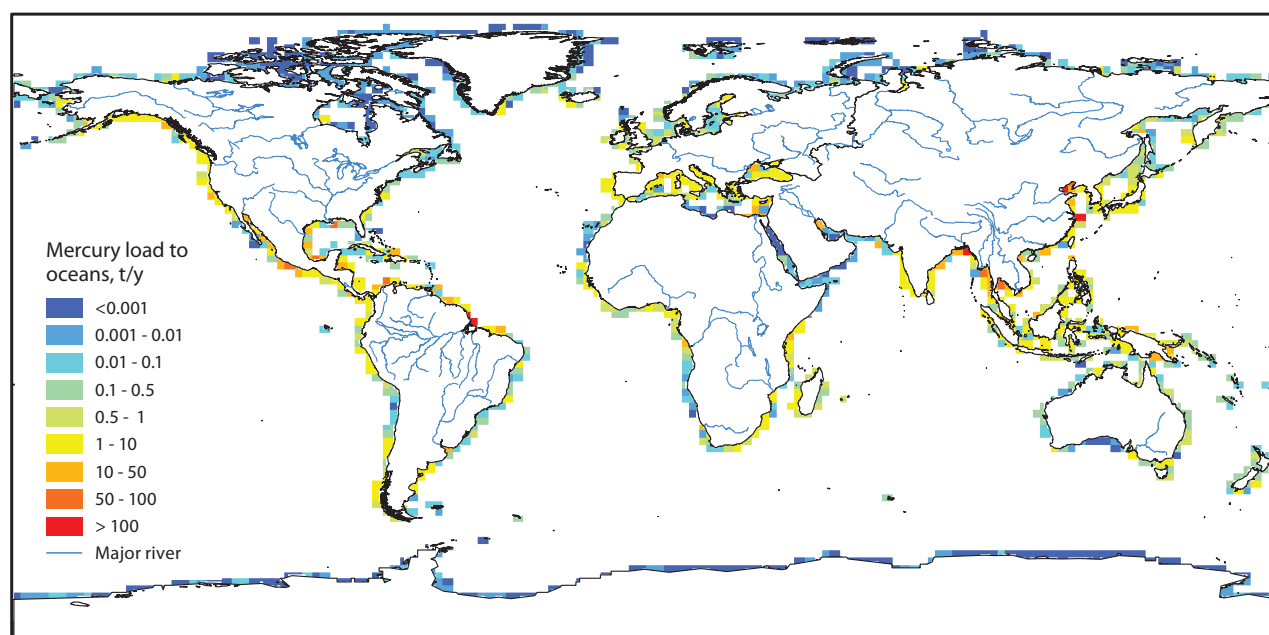


Figure 4.3. Average annual mercury fluxes (per grid cell) to oceans associated with suspended sediments. Source: based on ISLSCP data (Ludwig et al., 2011b) obtained from: <http://dx.doi.org/10.3334/ORNLDAAAC/1028>

and industrial processes. Depending on the source of Hg, production rate and release pathways at individual sites (direct releases to local terrestrial systems or Hg initially emitted to the atmosphere and then deposited in the surroundings of these sites), these sites can vary greatly in size (from hundreds of square metres to tens of square kilometres). Significant amounts of Hg are known to be transported to marine environments from these sites, especially because a big part of the world's urban and industrial areas are located near the coast. Due to the lack of environmental regulations in the past, at many of these locations, Hg was discharged for decades directly into nearby marine environments. One of the best known examples is Minamata Bay in Japan, where Hg-contaminated effluents were discharged for 30 years from a local acetaldehyde factory, causing the notorious Minamata disease in the local population eating contaminated seafood from the bay (Tomiyasu et al., 2006 and references therein). While the most contaminated sediments were removed from Minamata Bay, 1800 t of Hg are still present in the sediments of the Gulf of Trieste in the Northern Adriatic owing to drainage from the Idrija Hg mine region over the past 500 years. A mass-balance evaluation indicated that ~800 kg of this settled Hg re-enters the water column each year due to resuspension and to diffusion at the sea bottom-water interface (Rajar et al., 2004). Similarly, more than 140 t of Hg have accumulated in San Francisco Bay due to the historic mercury and gold mining activities in California (MacLeod et al., 2005). Since 1956, Hg has been continuously introduced into northern Haifa Bay in Israel from a nearby chlor-alkali plant. The total Hg input from this plant to the bay is estimated at ~22 t (Herut et al., 1996).

Inputs to aquatic environments from contaminated sites were calculated based on a recently constructed geo-referenced database of the global distribution of contaminated

sites (Kocman et al., 2013). In this database, the following most important categories of Hg sources and/or uses resulting in the occurrence of contaminated sites are included: locations of primary Hg mining, precious metal processing, non-ferrous metal production and various polluted industrial and urban sites. The locations of these sites are shown in Figure 4.4 and the categories briefly described below.

Primary mercury mining: Globally, approximately one million tonnes of Hg was extracted from various ore bodies, mostly in the region of the mercuriferous belts between the Mediterranean and central Asia (Hylander and Meili, 2003). It is believed that only a few percent of all Hg mined has escaped to the atmosphere so far (Hylander and Meili, 2003), the rest being available for remobilisation within the global Hg budget. The amount of Hg released to the environment, including aquatic systems, during mining and Hg ore production depends mostly on the technology used, which has changed considerably over the centuries. Based on the data on Hg production and smelting recovery reported by Kotnik et al. (2005) for the Idrija Hg mine in Slovenia in the period between 1960 and 1995, approximately 70% of total Hg lost into the environment was deposited in landfill as smelting residue, 25% was emitted into the atmosphere by flue gases and the remaining 5% released to the aquatic environment as condensation water. Applying these percentages to historical global Hg production (Hylander and Meili, 2003), results in approximately 175 000 t of Hg ore residues, 62 500 t of atmospheric emissions and 12 500 t of Hg directly released to aquatic systems in the past 500 years. This is clearly an oversimplification and might underestimate past Hg releases, as it is known that recovery of Hg in smelting has changed significantly (from 30% to over 90%) over the centuries (Kotnik et al., 2005).

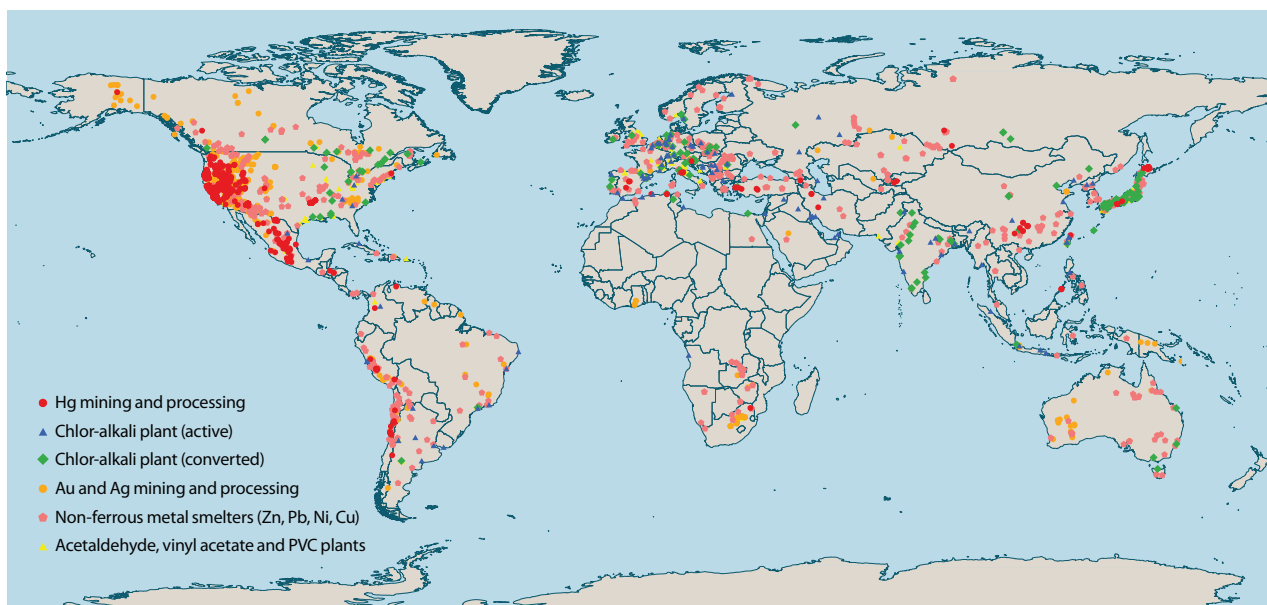


Figure 4.4. Global distribution of mercury-contaminated sites. Source: adapted from Kocman et al. (2013).

Chlor-alkali industry: According to the latest report by industry (UNEP, 2011e) there are approximately 100 active facilities worldwide with industrial Hg cell chlorine capacity. In addition, there are many locations where such facilities were either closed or shifted to Hg-free technology, but still act as a source of Hg to aquatic systems due to improper or inefficient remediation and waste disposal. Due to the large amount of Hg used in this sector, strongly elevated concentrations of Hg in soils can be found in the few kilometre radiuses surrounding these sites (e.g., Biester et al., 2002; Remy et al., 2003; Hissler and Probst, 2006).

Large scale precious metal processing: Historically, approximately half of all Hg mined has been used in gold and silver mining (Hylander and Meili, 2003), mostly in North and South America. It was estimated that total losses of Hg to all environmental compartments were 196 000 t in South and Central America and 61 380 t in the United States (Nriagu, 1994). In addition, due to the co-occurrence of Hg in gold and silver ores, during ore processing new Hg is released to the environment. For the reasons stated in the atmospheric part of this report (see Section 2.2.7), release estimates for this category also have large associated uncertainties.

Non-ferrous metal production: This category covers locations where zinc, copper, lead and nickel ores are processed. Contamination occurs due to the use of thermal methods during processing of these ores that can contain significant amounts of Hg. These locations are known sources of Hg (e.g., Li et al., 2008), but are extremely poorly documented, especially in terms of their surrounding aquatic systems.

Other industrial sites: Within this category are grouped locations of factories of acetaldehyde, vinyl chloride and vinyl acetate which used or may have used Hg as a catalyst. As with chlor-alkali plants, these sites are known sources of Hg pollution that can affect aquatic systems at distances exceeding 200 km (Ullrich et al., 2007).

Mercury input to aquatic systems from these sites depends on the level and extent of contamination, as well as local hydro-meteorological conditions that influence erosion and surface runoff processes. Due to the lack of detailed site-specific data, especially on substrate Hg content, the following approach was used. For each of the contaminated sites (mining and/or processing sites, industries intentionally using Hg as a catalyst), site-specific sediment yields were extracted from the GIS map of fluxes of total suspended solids available within the ISLSCP Initiative II Global Datasets (Ludwig et al., 2011b). Observations made for various case studies reported in the literature were used as the basis for selecting the size of the contributing area and the range of average soil Hg content that can be expected at these sites. In Table 4.4, the results of this approach and the assumptions made within individual contaminated site categories are shown.

4.3.2.2.3 Mercury releases as a consequence of land and water management practices

Agriculture

Historically, pesticides and fungicides containing Hg were widely used in agriculture, making this sector an important source of Hg for aquatic systems (Wang et al., 2004). In the 1960s, 2100 t of Hg were used in agriculture globally (Smart, 1968 in Wang et al., 2004). As far as is known, there are no recent data regarding quantitative assessment of Hg releases from this source. According to the report of the World Health Organization, mercurial compounds were widely used in agriculture through much of the 20th century, and although banned, some use was reported to have occurred in some parts of the world (e.g. Russia, Canada) even over the past decade (WHO, 2010 and references therein). Nowadays, huge amounts of sewage sludge are spread on land for agricultural use. For example, the total quantity (i.e., production) of sewage sludge in the 27 EU Member States is currently estimated at 10.13 million

Table 4.4. Calculated releases to aquatic systems from contaminated sites and assumptions made.

CAP: Chlor-alkali production with Hg-technology.

	Contributing area ^a	Hg soil content, mg/kg	Hg released, t/y
Primary mercury			
large	200 km ²		
medium	100 km ²	0.5 – 2.0	6.66 – 26.6
others	50 km ²		
CAPs	2–3 km radius	0.2 – 0.5	0.09 – 0.48
Non-ferrous metal	2–3 km radius	0.1 – 0.2	0.12 – 0.54
Precious metal			
mining	50–100 km ²	0.5 – 1.0	1.35 – 5.54
processing	2–3 km radius	0.2 – 0.5	
Other industries	2–3 km radius	0.2 – 0.5	0.06 – 0.33
Total			8.3 – 33.5

^a The size of the contributing area was selected based on the values used for calculating Hg emissions to the atmosphere from these sites as reported by Kocman et al. (2013).

tonnes (dry solids), and nearly 40% of this total is estimated to be used in agriculture (Milieu, 2010a). The Hg content of sewage sludge recycled to agriculture varies from country to country and ranges between 0.2 and 4.6 mg/kg (Milieu, 2010b). The most recent estimate of Hg introduced into agricultural soils in the EU27 is 4.4 t/y (BIO Intelligence Service, 2012).

Silviculture

Various practices used in forestry disturb the soil and so influence the mobility and availability of Hg for downstream aquatic systems. The increased transport is caused by increased erosion and changed hydrological pathways and yield through the catchment soils. Several studies in Fennoscandia and North America have reported increased transport of Hg and in some cases large increases in MeHg, but the variability in response is large (Bishop et al., 2009; Sørensen et al., 2009; Shanley and Bishop, 2012). Due to this large variability, there are no estimates of the total change in loading on surface waters due to forestry practices. However, there is some evidence of responses in fish concentrations (Garcia and Carignan, 2000) and it has been estimated that 10–25% of the Hg in fish in managed forest landscapes can be attributed to logging (Bishop et al., 2009).

In the pan-tropical regions, approximately 9.5 million km² of tropical forest area has been converted to agricultural land use, resulting in a significant increase in water yield (GWSP, 2008). Deforestation as a source of Hg pollution was recognised some time ago (Veiga et al., 1994), particularly in regions like the Amazon where deforestation for mining and agricultural purposes is intensive. A relationship between deforestation and Hg contamination of aquatic systems has been demonstrated in many studies (e.g., Farella et al., 2006; Mainville et al., 2006; Béliveau et al., 2009). Soil erosion and degradation enhanced by deforestation exposes the mineral horizon to the elements thus enhancing and accelerating Hg leaching (Mainville et al., 2006). Agriculture in the Amazon is based on the slash-and-burn principle that enables short-term enrichment of the soil with nutrients, but leads to loss

of Hg content, which is leached to rivers, entering the aquatic food chain, and posing a potential health threat to local populations (Farella et al., 2006). Soil Hg loss occurs rapidly after deforestation and is related to the massive cation input resulting from biomass burning (Béliveau et al., 2009). Associated Hg fluxes can be quite significant. It was reported that in addition to Hg use in gold mining activities, deforestation due to human colonisation and the consequent elevated soil erosion was responsible for 200–4600 µg/m²/y (depending on the thickness of soil) of Hg released to Amazonian rivers (Roulet et al., 1999). According to the most comprehensive forest review by the FAO to date (FAO, 2010), deforestation shows signs of decreasing in several countries but continues at a high rate in others. Around 13 million hectares of forest were converted to other use or lost through natural causes each year in the 2000s compared to 16 million hectares per year in the 1990s. Both Brazil and Indonesia, which had the highest net loss of forest in the 1990s, have significantly reduced their rate of loss, while in Australia, severe drought and forest fires have exacerbated the loss of forest since 2000 (FAO, 2010). The actual Hg loss due to deforestation depends on the loss and thickness of the organic horizon. If ~2000 µg Hg/m²/y is adopted as an average value globally (Roulet et al., 1999) and considering the area deforested reported for 2010, this would result in ~260 t Hg/y released to local aquatic systems. These releases are especially important as they bring new Hg to ecosystems that would otherwise be retained in soils.

Dam construction

On the global scale, significant amounts of the basin-scale sediment fluxes in regulated basins are potentially trapped in artificial impoundments; in the inventory by Vörösmarty et al. (2003) more than 600 artificial impoundments were categorised as large (> 0.5 km³ maximum storage capacity) and over 44 000 as smaller. Sediment trapping efficiency varies from basin to basin and locally can exceed 80%. The most heavily regulated drainage basins occur in Europe, followed by North America, Africa,

and Australia/Oceania (Vörösmarty et al., 2003). In this way, a significant proportion of the Hg associated with river sediments and transported downstream by rivers is trapped by these impoundments. Even more importantly, these impoundments cause increases in MeHg concentrations (in water, sediment and biota) by creating organic-rich anoxic deposits conducive to Hg methylation (Hines et al., 2000 and references therein). Assuming that 25–30% (or 4–5 Gt) of the total global sediment flux is intercepted by reservoirs (Vörösmarty et al., 2003), and comparing this with the total amount of Hg reaching the oceans (see Section 4.3.2.2.1), then ~400–1400 t of Hg annually is expected to be trapped globally by the reservoirs. However, it should be noted that there is a large uncertainty associated with this estimate, as sediment retention varies spatially as well as the Hg content of the sediment itself.

Offshore exploitation and exploration activities

In addition to offshore oil and gas operations (see Section 4.3.2.1.3 for details), there are various other offshore exploration and exploitation activities that can introduce Hg into marine environments. For example, deep sea mining can cause remobilisation and releases of Hg in/to oceans. The basic deep sea mining operations include picking up polymetallic nodules and separating them from the fine-grained seabed muds that host them, lifting them to the ocean surface; and separating them from the seawater and sediment entrained in the lift operation and transporting them to a metallurgical processing facility (Ponge, 2012). The associated environmental impacts are disruption of the sediments, and the discharges from the mining ships (Markussen, 1994). The former causes mobilisation of Hg trapped in the seabed sediments to the water column, as Hg is naturally associated with many of these minerals and can also produce conditions that favour methylation, while the latter is expected to

introduce wastewater enriched with Hg directly to surface waters. The extent of these activities can be seen from Figure 4.5 which shows the global distribution of deep seabed resources. Some other offshore activities that can affect oceans and from which it is reasonable to assume that Hg could be released to seas and oceans are ocean traffic, oil and gas pipelines, and offshore wind power installations (EC, 2012).

In general, Hg can be released to oceans due to its presence or use in specific processes associated with these activities. Moreover, during construction and operation of offshore installations, Hg previously immobilised in bottom sediments can be remobilised and released into the water column. Physical perturbation can cause Hg to be transported to environments that favour the production of MeHg. However, as far as is known, these environmental issues have not yet been addressed and no data exist that would make it possible to quantify Hg releases associated with these activities.

4.4 Inventory results

Among the individual sectors/categories for which there is enough information to provide a reasonable estimate of Hg released to aquatic environments, Hg use in ASGM seems to be by far the most important source of Hg. Total worldwide releases of Hg to both land and water associated with ASGM activities are estimated at over 880 t/y; however, how much of this Hg is later remobilised and enters aquatic systems cannot yet be determined. The global estimate of Hg release to water from other point sources totals 185 t/y. Of that, about half (89 t/y) is attributed to disposal of wastes from Hg-containing products, the rest being associated with non-ferrous metal production (especially gold, copper and zinc ore smelting), releases from

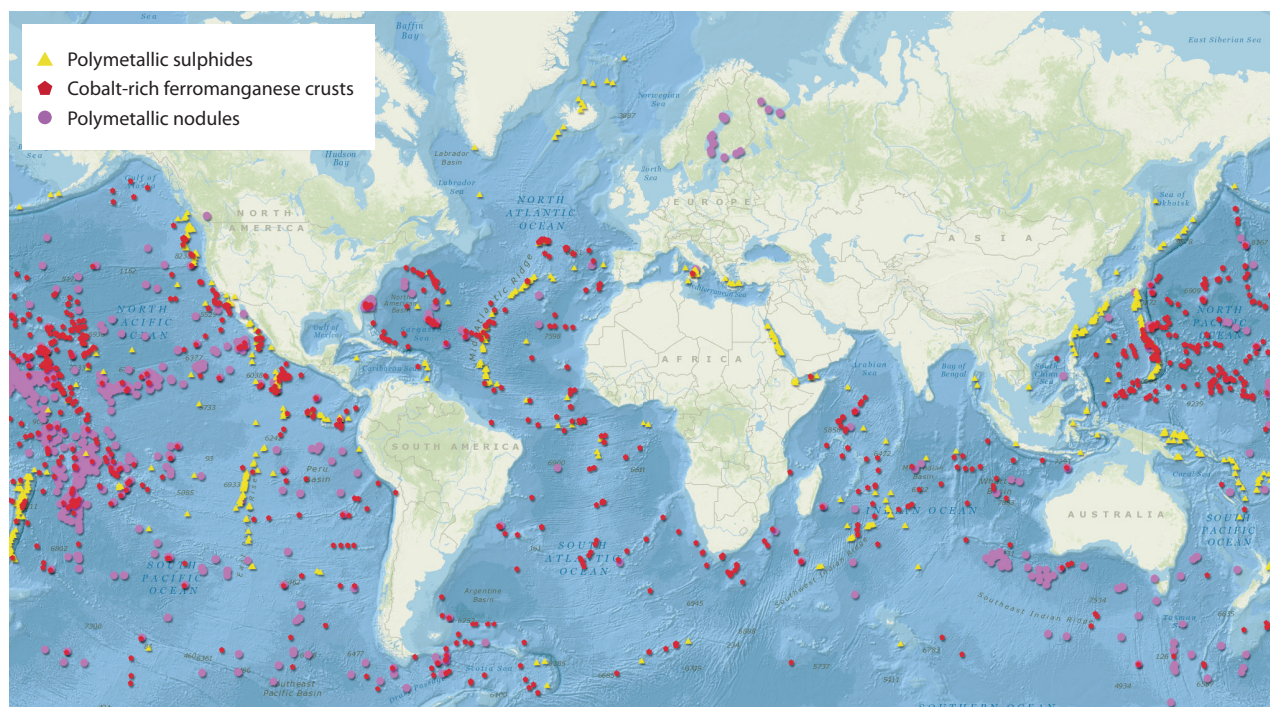


Figure 4.5. Global deep seabed resources. Source: obtained from ISA web GIS application online at: www.mapserver.isa.org/jm/GIS

the chlor-alkali industry and oil refining. In addition to these direct releases, remobilisation of Hg from various contaminated surfaces is estimated to be 8–33 t/y. Deforestation was also recognised as an important source of Hg with 260 t/y released into rivers worldwide. All this Hg released from the various point and diffuse sources enters local aquatic systems and is subjected to riverine transport. On its way to downstream aquatic systems, ~400–1400 t/y is expected to be trapped globally by reservoirs, while ~1200–3700 t of Hg is reaching coastal sites each year. Comparing these values with estimated natural releases from terrestrial environments (150–960 t/y), it is apparent that anthropogenic inputs are a substantial contributor to global Hg releases to rivers, lakes, and oceans.

4.5 Conclusions

4.5.1 Key findings on global releases of mercury to aquatic environments

1. The estimated releases and inputs of Hg to aquatic environments presented here are associated with large uncertainties. Still, the results indicate that anthropogenic sources contribute significantly (thousands of tonnes per year) to the global Hg budget. Based on current knowledge and understanding, it appears that diffuse inputs and direct releases from point sources are equally important.
2. Atmospheric deposition (see Chapter 3 for details) is the most important pathway for Hg to enter both the terrestrial and marine environment. However, in contrast to the oceans, Hg deposited on land is retained in large measure by soils and vegetation, representing a pool for further remobilisation.
3. While export of Hg from non-contaminated catchments does not usually exceed several $\mu\text{g}/\text{m}^2/\text{y}$, export of Hg from contaminated systems can reach hundreds of $\mu\text{g}/\text{m}^2/\text{y}$, affecting downstream aquatic systems at distances exceeding hundreds of kilometres.
4. Land management practices such as deforestation and agriculture can lead to enhanced and accelerated Hg leaching from soils, and in this way its entry to aquatic systems. Thus this remobilised Hg from historical natural and anthropogenic sources is introduced into aquatic environments and becomes part of the global cycle. Land management can act as a substantial contributor of Hg to aquatic systems.
5. Higher frequencies and magnitudes of extreme hydro-meteorological events as a result of climate change are very likely to lead to accelerated input of Hg to and transport within aquatic systems.
6. The present estimates of anthropogenic Hg inputs to aquatic environments revealed that due to its current use as well as to Hg historically accumulated in areas where ASGM activities are/were conducted, ASGM can be considered as the major single anthropogenic source of Hg for aquatic systems.
7. There are many other known anthropogenic activities, such as offshore exploitation and exploration, responsible for releases of Hg to aquatic systems, however these are not yet properly addressed in the scientific literature and, to date, there are no independent, openly available data that would make it possible to establish a global quantification of these releases.

4.5.2 Future needs/gaps in information

The estimates presented here have large uncertainties; mostly due to a lack of data in the literature reporting Hg releases to aquatic systems. Extrapolation of releases from site-specific case studies does not take site/sector specific conditions into account. Therefore, in order to reduce the uncertainties the following approach is suggested:

- The mobility and consequent transport of Hg from its source to aquatic environments depend greatly on the chemical form of the Hg that in combination with site-specific environmental conditions (climatic conditions and the topography of the site) determine its reactivity and bioavailability (toxicity). As only limited information is currently available, the generalisations and assumptions stated in this report had to be made for estimating the global releases of Hg to aquatic systems. Obviously, this is an oversimplification of reality that introduces additional uncertainty in the estimates and should therefore be studied in more detail and addressed in future models and scenarios.
- Information regarding global releases of Hg to aquatic systems is still incomplete, also due to the fact that data are not available for some categories that might be important contributors (e.g., landfills, cement production, waste incineration, coal fired power plants etc.). While contributions from these categories are usually considered negligible relative to atmospheric inputs, the number of these sites and installations globally is significant. Releases of Hg to local aquatic systems from such sites may, therefore, also be significant. Similarly, there is a need for more reliable Hg data from offshore exploration and exploitation activities.
- Systematic and harmonised monitoring of Hg releases and inputs to aquatic systems is required, especially in contaminated systems where Hg loads are much harder to predict relative to non-contaminated systems.
- Harmonised approaches for both measurement and reporting of Hg releases from anthropogenic point sources are needed to ensure comparability of data at the global scale.

5. Aquatic Pathways, Transport and Fate

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Contributors: David Kocman, Milena Horvat, John Munthe

5.1 Introduction

Understanding mercury's aquatic pathways and fate is important because naturally-occurring processes within aquatic ecosystems convert the inorganic forms of Hg (Hg^0 and Hg^{II}), which dominate the airborne and aquatic Hg releases, into the considerably more toxic form, monomethyl mercury (MeHg), which accumulates in marine and freshwater animals. The majority of the human exposure and health risk associated with Hg comes from consumption of marine foods (fish and marine mammals) containing high levels of MeHg (Mahaffey et al., 2004; Booth and Zeller, 2005; Sunderland, 2007; INAC, 2009; AMAP, 2009). Therefore, this chapter concentrates on the pathways and fate of Hg in the world's oceans and its temporal trends in marine food webs. However, freshwater systems in some regions can be important sources of fish for human consumption, especially for subsistence and recreational fisherman and for some indigenous communities. Certain freshwaters (rivers downstream from artisanal gold mining, chlor-alkali facilities, landfills and other point sources of Hg; lakes receiving elevated rates of atmospheric Hg deposition; and reservoirs) may also be significant locations of Hg contamination and subsequent human health risk. Other ecosystems may be especially sensitive even to low-level Hg inputs because of environmental factors such as low pH, high organic matter, large areas of wetlands and regular wet/dry

inundation cycles which enhance MeHg formation (Driscoll et al., 2007). Hence, the pathways and fate of Hg in freshwater environments are also described.

5.2 Aquatic pathways and fate

The generalised aquatic pathways of total Hg in the environment, and the sites of MeHg production and decomposition in aquatic ecosystems is portrayed in Figure 5.1. Although the biota and the organic and inorganic composition of freshwater and seawater differ, many of the important processes of the biogeochemical cycle of Hg (such as methylation, demethylation, the dominance of atmospheric deposition inputs, and the importance of organic particle scavenging of Hg to sediments) are common to all aquatic systems (Fitzgerald and Lamborg, 2007). Lakes and rivers, though, are generally more affected by inputs from their catchments, and by sediment processes including MeHg production because the surface area of sediment relative to water volume is large compared to oceans. Generally, inorganic Hg^{II} in dissolved or particulate form dominates the total Hg present in most waters (e.g., Mason et al., 1994; Fitzgerald et al., 2007; Jeremiason et al., 2009). Dissolved gaseous elemental Hg (DGM ; Hg^0) is typically a minor constituent (<30%) of the total Hg pool, and dissolved MeHg (the most toxic and bioaccumulative of the various Hg species) and dimethyl mercury (DMeHg) are similarly often <20% of total Hg. However, both methylated forms combined may be present at concentrations up to 50% of total Hg in some settings (e.g., the Mediterranean Sea [Cossa et al., 2009]; North Pacific Ocean [Sunderland et al., 2009]; Beaufort Sea [Wang et al., 2012b]). In freshwater and many coastal environments, methylation of inorganic Hg mostly occurs in sediments because of the high microbial activity and near-surface anaerobic zones which

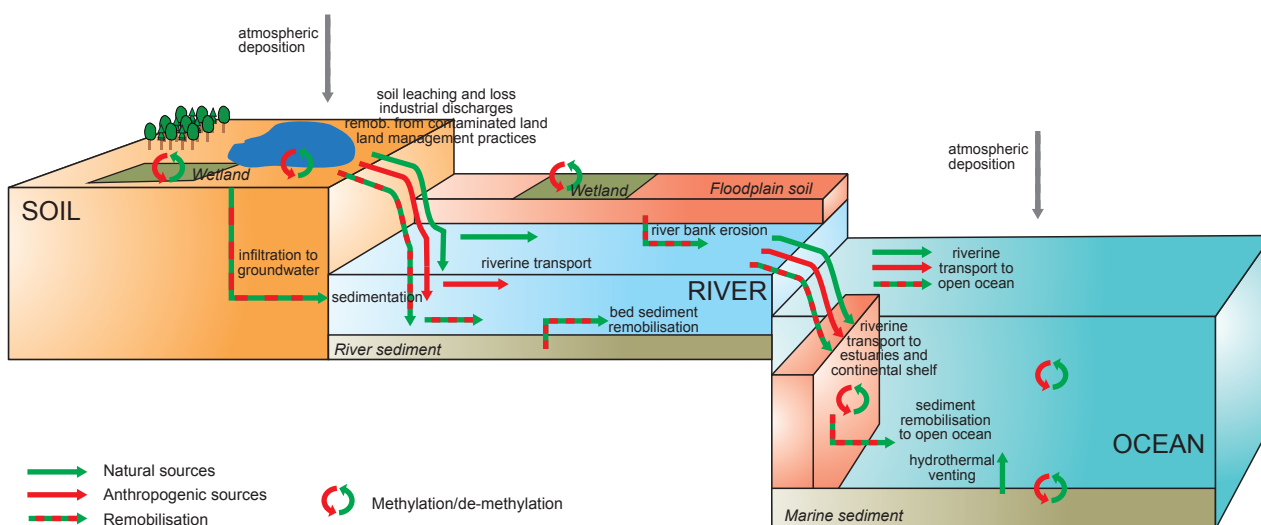


Figure 5.1. Transport pathways of mercury, and general sites of methylation and demethylation, in aquatic systems.

favour sulphate-reducing bacteria. Methylation of inorganic Hg may also occur in anaerobic depths of the water columns of lakes and oceans, but in the ocean methylation occurs to a large degree within the surface to intermediate depths of the water column where anoxia is not known to occur (Fitzgerald and Lamborg, 2007; Sunderland et al., 2009; Lehnher et al., 2011; Mason et al., 2012). The principal pathways by which Hg is lost from aquatic systems in general are reduction of inorganic HgII to gaseous Hg0 and its volatilisation to air, and burial of particle-associated HgII in sediments (Fitzgerald et al., 2007; Jeremiason et al., 2009; Qureshi et al., 2009). Organic matter (OM) has a high affinity for inorganic Hg and MeHg because of their binding by thiol (SH-) groups present in OM, and therefore dissolved and particulate OM strongly influence the mobility and geochemistry of Hg throughout aquatic ecosystems. In some environments, and particularly in sediments and estuarine waters, binding to inorganic sulphide ligands is also important (Fitzgerald et al., 2007).

5.2.1 The oceans

Model simulations suggest that anthropogenic impacts are generally greatest in the surface mixed layer of the ocean (Soerensen et al., 2010; Strode et al., 2010; Figure 5.2).

Throughout this document, the terms ‘surface waters’ and ‘mixed layer’ are used to refer to the top 100 m of the ocean, while ‘subsurface’ or ‘intermediate’ waters refer to depths below the mixed layer but above the permanent thermocline, that is, from 100 m to typically <1000 m. In the subsurface waters, penetration of anthropogenic Hg is varied and complicated by the regionally-variable lateral and vertical movement of water masses through upwelling and deep-water formation in different ocean basins, and because of sinking and decomposition of Hg-containing particulate material (Mason and Sheu, 2002; Sunderland and Mason, 2007; Strode et al., 2010). Estimates of anthropogenic Hg enrichment vary among models that have different spatial and temporal resolution and consider different transport processes, and evaluation of these models is constrained by limited measurements. One recent estimate (Streets et al., 2011) which includes the impact of human-related Hg releases during the past 500 years suggests that Hg concentrations in the surface mixed layer have increased by a factor of 2–3 over that time while the deep ocean has increased by about 40%. These values are greater than those shown in Figure 5.2, where the increases are estimated for only the past 100 years. Overall, anthropogenic Hg enrichment of deep ocean water is

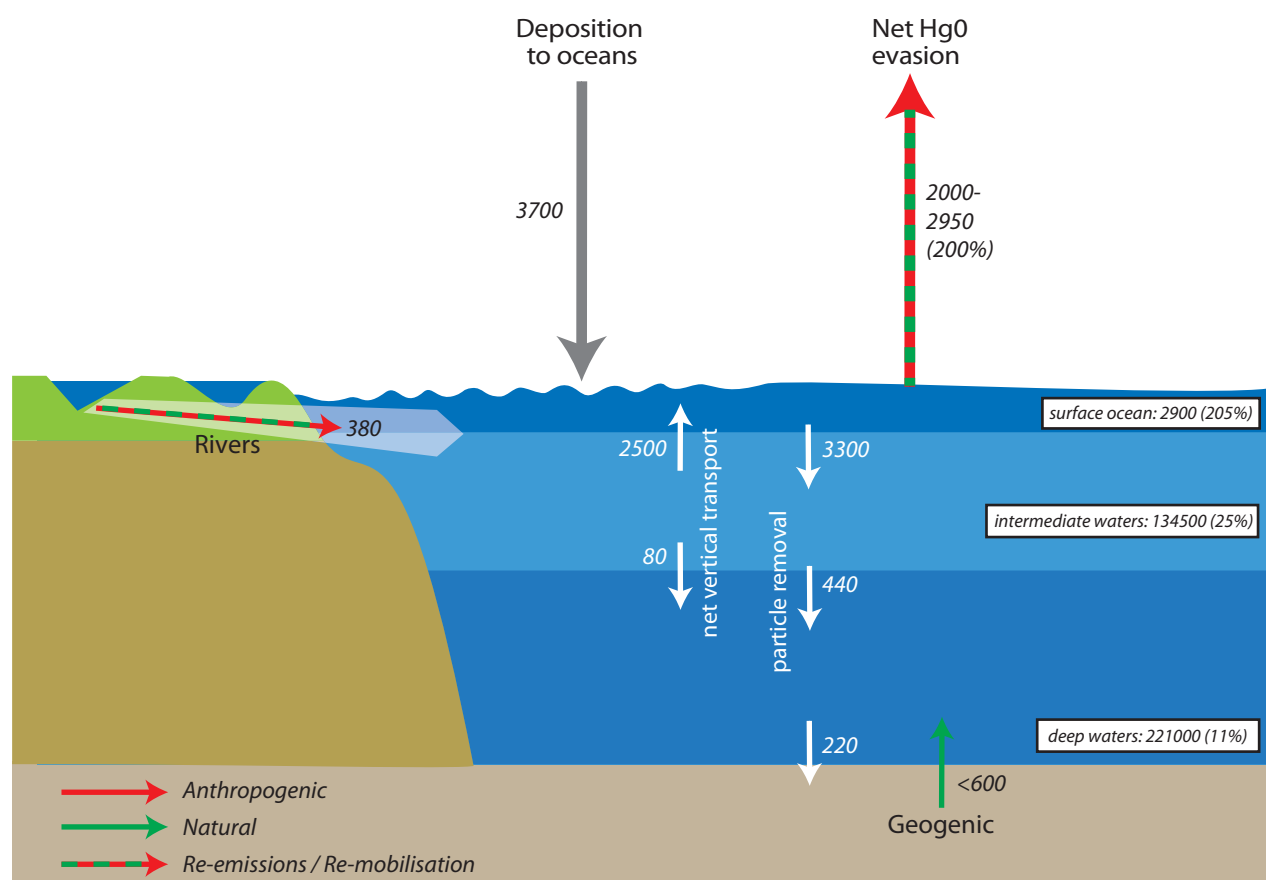


Figure 5.2. A recent estimate of the inventories and fluxes of mercury into and within various layers of the Earth's oceans. Source: adapted from Mason et al. (2012); original Mmol units converted to tonnes by a factor of 200.6. Inventories are in tonnes, and fluxes in tonnes per year. The model is based on simulations using the GEOS-Chem global model, and building on previous studies (Sunderland and Mason, 2007; Selin et al., 2008; Holmes et al., 2010; Smith-Downey et al., 2010; Soerensen et al., 2010). Inventories in different ocean depths shown in square boxes (surface oceans: 0–100 m depth; intermediate waters: 100–1000 m; deep waters below 1000 m depth). The percentage values in brackets are the estimated increases in seawater inventories in the past 100 years due to anthropogenic activities.

much smaller than surface and subsurface waters due to the long time-scales for lateral and vertical transport to the deep ocean (Sunderland and Mason, 2007), which has an overall mixing time of ~1000 years. Understanding the impacts of human activities on MeHg concentrations in marine fish, marine mammals and other marine foods, requires combining knowledge of the time-scales necessary for penetration of anthropogenic Hg in the vertical marine water column with identification of the dominant regions where inorganic Hg is converted to MeHg.

5.2.1.1 Marine inorganic mercury pathways and fate

Sources of Hg to oceans include inputs from ocean margins (rivers, estuaries), groundwater, diffusion from benthic sediments, undersea hydrothermal vents, and direct atmospheric deposition. Except for hydrothermal vents, all of these inputs comprise mixtures of Hg from anthropogenic, natural and re-emitted/re-mobilised sources (see Chapter 4 for detailed discussion of releases to aquatic systems). The most recent modelling effort suggests that total wet and dry deposition to global oceans as a whole in 2008 was 3700 tonnes (Figure 5.2; Mason et al., 2012).

Models and measurements concur that direct atmospheric deposition is the dominant pathway of Hg entry (>80% of total assuming hydrothermal vents contribute 300 t/y; Figure 5.2) (Mason and Sheu, 2002; Dastoor and Larocque, 2004; Selin et al., 2007, 2008; Strode et al., 2007; Sunderland and Mason, 2007; Holmes et al., 2010b; Soerensen et al., 2010; Mason et al., 2012). Exceptions to this general pattern occur in smaller semi-enclosed basins such as the Mediterranean Sea (Rajar et al., 2007) and the Arctic Ocean (Outridge et al., 2008), in which contributions from rivers, coastal erosion or seawater exchange reduce the atmospheric contribution to about 50% of total inputs.

Other Hg pathways to oceans are much smaller on a global basis. Using available discharge and sediment load data on the world's largest 927 rivers (Ludwig et al., 1996; Dai and Trenberth, 2002), Sunderland and Mason (2007) showed that the total Hg load from rivers to estuaries is large (>2800 t/y) but that only a small portion of this Hg is transported offshore (~380 t/y, range 240–480), with the remainder trapped by particle settling to estuarine sediments. Riverine inputs can be regionally important. For example, on a basin-wide scale, Hg inputs from rivers ranged from 25% to >50% of the inputs from atmospheric deposition in the South Atlantic Ocean, North Pacific Ocean, and Mediterranean Sea. Conversely they comprise a negligible fraction of inputs in the Arctic, North Atlantic, South Pacific and Indian Oceans (Rajar et al., 2007; Sunderland and Mason, 2007; Outridge et al., 2008).

Limited studies suggest that groundwater Hg inputs and benthic sediment fluxes provide relatively small additions of Hg to the global oceans (~100–800 t/y). Groundwater Hg fluxes into global oceans were derived by assuming groundwater inputs make up ~10% of surface flow (Cossa

et al., 1996; Laurier and Mason, 2007; Mason et al., 2012). However, these sources may be regionally significant in some semi-enclosed seas, estuaries and coastal bays with high groundwater outflows, and in seas over active tectonic areas or with a high proportion of continental shelves (e.g., the Mediterranean Sea; Rajar et al., 2007). Dissolved gaseous Hg concentrations exceeding 100 pg/L have been found in extensive areas of deeper water of the Mediterranean Sea, suggesting a benthic source (Horvat et al., 2003; Kotnik et al., 2007), while the sources and levels of DGM in other oceans are areas of active research.

Inputs of Hg from hydrothermal vents are estimated to be <600 t/y (<20% of atmospheric inputs) on a global basis (Lamborg et al., 2006; Mason et al., 2012). Data from four vent locations representing a wide range of geologies showed very high total Hg concentrations in vent fluids (Lamborg et al., 2006), however, scavenging during precipitation of solids removed Hg from vent fluids once they entered seawater, similarly to iron, manganese and other metals (German and Von Damm, 2004). Local enrichment of Hg in hydrothermal-associated mineral deposits and sediments is further evidence for this removal (e.g., Dekov, 2007). In addition, there is the potential for the release of dissolved inorganic Hg from deep ocean sediments. However, various estimates suggest that these inputs are small (Hollweg et al., 2010; Mason et al., 2012).

Gas exchange at the air-water interface is the major removal process for Hg from oceans (see Figure 5.2; Mason et al., 1994, 2001; Fitzgerald et al., 2007; Sunderland and Mason, 2007; Andersson et al., 2011). On a global basis, most (~70%) of the HgII deposited in marine ecosystems is re-emitted to the atmosphere in gaseous form (elemental Hg₀ predominantly, but also some DMeHg; Mason and Sheu, 2002; Soerensen et al., 2010; Corbitt et al., 2011). Net biotic and photochemical reduction of HgII to Hg₀ occurs in surface waters, and subsequent evasion of Hg₀ reduces the pool of potentially bioavailable HgII that may be converted to MeHg and bioaccumulated by marine organisms. A second effect of this evasion is to reduce the amount of Hg diverted by particle scavenging and vertical transport into intermediate and deep waters, where most of the methylation occurs (Mason et al., 2012), and ultimately into sediments. This gas exchange therefore simultaneously prolongs the lifetime of Hg cycling through the atmosphere and biosphere, and partially mitigates the impact of anthropogenic Hg inputs on marine food webs. The prolonged recycling in the atmosphere–biosphere loop, however, also extends the period of impact of any release of Hg to the atmosphere (Smith-Downey et al., 2010).

Any changes in either the efficiency of net reduction in surface waters or the rate of gas exchange will impact the relative rate of change in surface Hg concentrations as well as in atmospheric Hg concentration. One example is the effect of sea-ice cover in the Arctic Ocean which impedes DGM flux into air so that substantially higher DGM concentrations are found under ice-covered areas (Andersson et al., 2008). Changes in the rate of Hg removal from the surface ocean

by particle scavenging, resulting from variations in primary productivity, could also affect the extent of re-emission to the atmosphere. In addition, changes in oxidant levels (such as ozone) of the atmosphere will affect the rate of net oxidation of Hg in the atmosphere and therefore the rate of deposition of Hg to the ocean.

5.2.1.2 Marine methylated mercury pathways and fate

Both MeHg and DMeHg, here collectively referred to as Σ MeHg, are present in seawater at detectable concentrations in every region of the world's oceans (Fitzgerald et al., 2007; St. Louis et al., 2007; Cossa et al., 2011). Figure 5.3 presents a global budget for MeHg in the world's oceans. Possible sources of MeHg include production in coastal and shelf sediments (Hammerschmidt and Fitzgerald, 2004, 2006a,b), emissions from hydrothermal vents and remobilisation from deep-sea sediments (Kraepiel et al., 2003), and *in situ* water column methylation and DMeHg decomposition processes (Mason and Fitzgerald, 1990; Sunderland et al., 2009; Heimbürger et al., 2010; Cossa et al., 2011; Lehnher et al., 2011). Evidence strongly suggests that DMeHg is mostly formed by microbial activity during *in situ* water column processes involving inorganic Hg (Fitzgerald et al., 2007).

Atmospheric inputs are likely to be a small fraction of total MeHg supply to the marine environment, ranging from 14–30 t/y (average 20 t/y), assuming that MeHg is 0.5% of total Hg in deposition (Mason et al., 1997; Sunderland and Mason, 2007; Sunderland et al., 2010; Figure 5.3). Evasion of volatile DMeHg to the atmosphere is estimated at 2 t/y (Mason and Benoit, 2003). Even though Σ MeHg in some hydrothermal fluids can range up to 100% of total Hg, especially from rock strata rich in organic matter (Lamborg et al., 2006; Crespo-Medina et al., 2009), hydrothermal vents generally contribute

<10 t of Σ MeHg annually to the world's oceans (Mason et al., 2012). The transport of riverine MeHg inputs offshore is estimated at 20 t/y, based on 5% of total Hg being MeHg and assuming that 90% of riverine input is trapped by settling particles in estuarine and coastal sediments (Sunderland and Mason, 2007).

Estimates of the inputs of dissolved MeHg from coastal and shelf sediments to the open ocean range from 2–30 t/y (Cossa et al., 1996; Hammerschmidt and Fitzgerald, 2006a; Hollweg et al., 2010). Part of this variation is an artefact of methodology, with many of the lower estimates being based on simple diffusion models and porewater concentration gradients. Studies with benthic flux chambers provided flux values that are up to an order of magnitude higher than the diffusive estimates (e.g., Gill et al., 1999; Choe et al., 2004; Hammerschmidt and Fitzgerald, 2008). Given the estimate by Fitzgerald et al. (2007) that the fraction of MeHg fluxing from sediments is ~8% of the total Hg sediment depositional flux, and using the global Hg deposition flux to shelf/slope sediments of 580 t/y (Sunderland and Mason, 2007), the MeHg flux from sediments was estimated by Mason et al. (2012) at 42 t/y (see Figure 5.2). However, combining the two approaches suggests that the value may be <40 t/y.

The deposition of MeHg to shelf and slope sediment (~30 t/y, see Figure 5.2), estimated using the fluxes reported by Sunderland and Mason (2007) and 5% MeHg in sedimentary material, is of the same order as the sediment inputs to seawater, suggesting little net transfer overall from coastal sediments to the ocean. Sediment resuspension is a potential source of MeHg in some locations (Kim et al., 2008), and could potentially increase the magnitude of net MeHg flux locally (Benoit et al., 2009; Sunderland et al., 2012). Such data are extremely limited for shelf environments. Relatively high benthic fluxes of MeHg have been estimated for estuarine

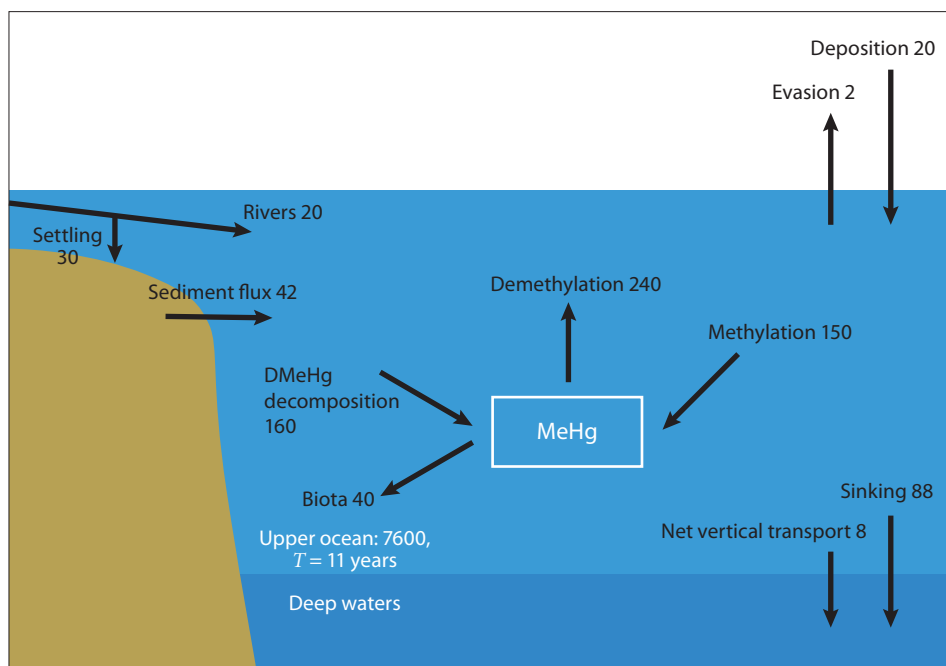


Figure 5.3. Budget for the sources and sinks of monomethyl mercury (MeHg) in the upper ocean (defined as waters above the permanent thermocline, typically <1000 m depth). Source: adapted from Mason et al. (2012). DMeHg – dimethyl mercury. Original Mmol units converted to tonnes by a factor of 200.6. Inventories (in white) are in tonnes, and fluxes (in black) in tonnes per year.

environments such as Baltimore Harbour, Long Island Sound, Chesapeake Bay, San Francisco Bay, and New York Harbour (Choe et al., 2004; Hammerschmidt et al., 2004, 2008; Mason et al., 2006) and for other contaminated environments (e.g., Gulf of Trieste; Covelli et al., 1999), whereas more limited data from shelf and slope sediments confirm that fluxes are lower than in estuaries (Hammerschmidt and Fitzgerald, 2006a; Hollweg et al., 2009, 2010).

The net input to open oceans from coastal environments is likely to vary depending on the extent of the continental shelf and other factors including organic matter and Hg loadings, and hydrologic exchange rates. Sunderland et al. (2010), for example, demonstrated that sediment sources of MeHg were not important in the Bay of Fundy, Canada, and that most MeHg was supplied from external sources (exchange with the North Atlantic Ocean, and river inputs). Similar results can be inferred from mass balance estimates for the inshore coastal sediments of the Gulf of Mexico (Liu et al., 2009), and for the Hudson River estuary, New York (Balcom et al., 2010). However, sediments contributed a much greater fraction in other estuaries, such as Chesapeake Bay and Long Island Sound (Mason et al., 1997; Hammerschmidt and Fitzgerald, 2006b).

The flux estimates discussed above indicate that sources of MeHg external to the ocean itself (i.e., riverine inputs, coastal sediments and atmospheric deposition, totalling ~80 t/y) are insufficient to account for the MeHg sinks in the upper oceans (totalling ~380 t/y, see Figure 5.2). These sinks include accumulation into biota and removal by fisheries, photochemical and biological degradation into inorganic Hg, and net removal to deep ocean waters and sediments. This discrepancy suggests that production within the ocean is important. The potential *in situ* sources of MeHg are: production in and diffusion from deep ocean sediments, and production within the water column.

There are few measurements of MeHg in deep ocean sediments and porewater (e.g., Gobeil et al., 1999; Ogrinc et al., 2007; Kading and Andersson, 2011), making estimates of the flux of methylated Hg from these deposits into seawater difficult. Available data indicate very low average concentrations of total Hg in deep ocean sediments, and percentages of MeHg that are equivalent to or less than those in sediments on the continental margins. Studies have estimated for the margins that <8% of the HgII deposited is converted to MeHg and remobilised to overlying water (Fitzgerald et al., 2007). Mercury species concentration data for shelf and slope sediments support these estimates (Hammerschmidt and Fitzgerald, 2006a; Hollweg et al., 2009). This information crudely constrains the global flux of MeHg from deep sea sediments to <16 t/y, which is a minor contribution to the overall budget (Mason et al., 2012).

Pronounced subsurface maxima in both MeHg and DMeHg have been reported from many ocean basins (Kim and Fitzgerald, 1988; Mason and Fitzgerald, 1990, 1991, 1993;

Mason et al., 1998; Mason and Sullivan, 1999; Horvat et al., 2003; Kirk et al., 2008; Cossa et al., 2009, 2011; Sunderland et al., 2009, 2011; Heimbürger et al., 2010; Bowman et al., 2012; Hammerschmidt and Bowman, 2012). The most conservative explanation for these vertical profiles is the *in situ* formation of MeHg at intermediate depths in association with the natural decomposition of organic matter (Mason and Fitzgerald, 1993; Mason et al., 1998; Mason and Sullivan, 1999; Cossa et al., 2009, 2011; Sunderland et al., 2009). The link to organic carbon degradation is demonstrated by the relationship between MeHg concentrations and the extent of organic carbon remineralisation (Sunderland et al., 2009), by correlations between MeHg and apparent oxygen utilisation (another measure of carbon degradation; Mason and Fitzgerald, 1990, 1993; Mason and Sullivan, 1999; Heimbürger et al., 2010; Cossa et al., 2011), and by consideration of Redfield-type ratios between MeHg and phosphate in particulate organic matter in surface and intermediate waters (Cossa et al., 2009).

A recent finding that the kinetic processes producing and degrading MeHg are very rapid within the Arctic Ocean may have significant implications for marine MeHg distribution and bioavailability globally. Lehnher et al. (2011) used bottle incubations with stable Hg isotopes to demonstrate that methylation and demethylation in Arctic seawater occurred with half-lives measured in days. By contrast, the global mass balance for MeHg suggests an average residence time of 11 years (see Figure 5.3). The explanation for this difference may be that some locations exhibit much more rapid methylation/demethylation kinetics than the global average figures suggest. A logical consequence of this rapid production and destruction is that MeHg transport is laterally and vertically limited in certain environments, such that sharp, local gradients of dissolved MeHg can occur (Lehnher et al., 2011). Furthermore, the exposure of marine biota to MeHg under highly kinetic systems like this must ultimately be controlled by the capacity for methylation of local inorganic Hg in conjunction with organic matter production and degradation (Wang et al., 2012b).

In addition to direct formation of MeHg from inorganic HgII, remineralisation of sinking particles and decomposition of DMeHg are also potential sources of MeHg (Mason and Fitzgerald, 1993; Mason and Sullivan, 1999). Present understanding suggests that DMeHg decomposition and inorganic Hg methylation contribute roughly equal amounts of MeHg (160 and 150 t/y, respectively) to the upper ocean MeHg pool (Figure 5.2). If MeHg is also produced in the surface mixed layer (as observed by Lehnher et al., 2011), the low concentrations there suggest that production is balanced by demethylation (Hammerschmidt and Bowman, 2012), and to a lesser extent by bioaccumulation into food webs. Current evidence suggests that the vertical flux and remineralisation of particulate MeHg into deeper waters contributes little to intermediate water MeHg levels (Cossa et al., 2009). Currently, there is little information and consensus on the regions of maximum production of MeHg, although

there is a general agreement that the formation is linked to the decomposition of organic matter. Anaerobic bacteria are the major Hg methylating organisms in coastal and freshwater sediments but it is unclear whether they are important in the marine water column because methylation there appears to be most closely linked to the aerobic metabolism of organic carbon (Sunderland et al., 2009; Heimbürger et al., 2010). Alternatively, anoxic micro-environments may possibly be created inside sinking particulate organic matter. The microbial pathway responsible for seawater Hg methylation has yet to be confirmed.

Identifying the important locations, processes and net balance between rates of methylation and demethylation in the world's oceans should be a high research priority because this knowledge could help to explain the spatial, temporal and taxonomic variations of MeHg content in marine food webs. For example, in the northern Adriatic region, net Hg methylation in coastal lagoon sediments was controlled by rapid demethylation and the bioavailability of inorganic Hg which was affected by adsorption and precipitation processes (Hines et al., 2012). On the other hand, methylation in offshore marine sites correlated with sulphate reduction rates (Hines et al., 2006). The estuarine to marine gradient in the northern Adriatic is therefore an example of a dynamic system exhibiting horizontally variable rates of microbial activity and Hg transformations that create 'hotspots' of MeHg accumulation which are controlled differently in each region (Hines et al., 2006).

Demethylation, either photolytically or microbially, is the major removal process for MeHg in the upper ocean, based on reported rates of decomposition (Mason and Sullivan, 1999; Monperrus et al., 2007; Whalin et al., 2007; Lehnher et al., 2011). Overall, the residence time of MeHg is relatively short (~11 years on average) for the upper ocean based on the fluxes in Figure 5.3. This residence time is comparable to the horizontal mixing times of subsurface waters. Therefore it is unlikely that MeHg formed in coastal environments can be transported sufficiently offshore to be a major source for pelagic ocean ecosystems, especially if the very rapid demethylation rates measured in some marine waters (e.g., Lehnher et al., 2011) are widely applicable. There is the potential for 'bioadvection' of MeHg due to either feeding of offshore fish in coastal environments, or to migration of biota (Fitzgerald et al., 2007). But such transport is bidirectional through the transport of MeHg in biota into and away from estuaries and rivers (e.g., the spawning migration and death of salmon [Sarica et al., 2004]).

The other important fate pathway for MeHg in seawater is uptake into marine food webs. Although only 40 t/y is estimated to follow this pathway, compared to 240 t/y going into demethylation (see Figure 5.2), it is this fraction which presents health risks to marine wildlife and the human consumers of seafood. In terms of its accumulation in food webs, MeHg is especially problematic compared to the inorganic and gaseous elemental Hg dissolved in seawater,

for several reasons. First, dissolved MeHg is accumulated by phytoplankton at the base of food webs several times more efficiently and rapidly than inorganic Hg (Mason et al., 1996). The MeHg bioaccumulation step from water to phytoplankton and other seston can be a factor of 10^4 or greater and represents the largest single increase for MeHg concentrations in aquatic ecosystems (Miles et al., 2001; Baeyens et al., 2003). Second, the absorption of MeHg from the gastro-intestinal tract of animals is significantly more efficient than for inorganic Hg (Berlin, 1986; Scheuhammer, 1987). Third, MeHg is the only Hg form to biomagnify in concentration as it progresses from one trophic level to the next in food webs (Campbell et al., 2005; Fitzgerald et al., 2007). Thus, the fraction of MeHg increases progressively with trophic level, typically reaching over 90% of total Hg in the flesh (muscle) of predatory fish and other high trophic level species such as marine mammals (Morel et al., 1998; Campbell et al., 2005) which are consumed by humans. Biomagnification is a key part of the explanation why some indigenous populations that consume top marine predator species have among the world's highest Hg exposures (and blood Hg levels) (AMAP, 2009). Because the magnitudes of atmospheric and waterborne inputs of Hg often do not exhibit a linear relationship with methylation rates and bioavailability, monitoring of environmental Hg requires a comprehensive, spatially-integrated assessment, including high trophic level organisms such as predatory fish and marine mammals as well as abiotic compartments (Evers et al., 2008).

5.2.2 Freshwater environments

5.2.2.1 Riverine pathways and fate

Riverine fluxes of Hg are the consequence of the presence of Hg in terrestrial compartments and its transport due to the processes of erosion and surface runoff within catchments. Globally, total Hg flux in rivers is predominantly associated with suspended particulate matter derived from catchment soils, vegetation, and weathering of exposed rock (Grigal, 2002; Leitch et al., 2007; Brigham et al., 2009; Schuster et al., 2011). The retention of Hg in terrestrial compartments and its delivery to aquatic ecosystems depend on the characteristics of watersheds, such as their size and topography, watershed-to-surface water ratios, land cover and land use (Munthe et al., 2007). Moreover, these ecosystem-specific variables influence the form of Hg delivered and, consequently, its bioavailability and uptake into aquatic food webs (Munthe et al., 2007). Spatial distribution and levels of Hg within the terrestrial part of the catchments are also important and can vary considerably from site to site, depending on the natural and anthropogenic sources of Hg present, soil organic matter content, and other physiographic features of the catchment. For example, low soil Hg concentrations in boreal and Arctic ecosystems are driven by very low atmospheric deposition rates (Smith-Downey et al., 2010). Geostatistical analysis revealed highly

variable concentrations of Hg in European topsoils (from 2 to 100's ng/g) that are directly related to human activities such as agriculture (use of fertilizers, manure and agrochemicals) and correlate with the distance to urban and industrial areas (Lado et al., 2008). Similarly, due to atmospheric loading, mining activities, or urban contamination, contaminated stream systems are found throughout the United States (Scudder et al., 2009). Concentrations of total Hg in bed sediments and water in these streams, as a result of soil leaching and erosion, vary over a wide range from 0.84–4.52 ng/g and from 0.27–446 ng/L, respectively (Scudder et al., 2009).

In a comprehensive review, Grigal (2002) emphasised the influence of catchment characteristics such as vegetation and topography, the size of the catchment (lower flux with increasing catchment size), and the percentage of wetland area as the most important characteristics of the catchment influencing the input and speciation of Hg entering aquatic systems. Annual inputs of Hg reported for catchments of varying sizes are mostly in the range 1–3 $\mu\text{g}/\text{m}^2/\text{y}$ (Grigal, 2002; and references therein). Similar inputs (0.87–4.36 $\mu\text{g}/\text{m}^2/\text{y}$) were reported for eight streams in the USA where atmospheric deposition was the main input pathway of Hg (Brigham et al., 2009). Transport of Hg in these streams was found to be mainly controlled by dissolved organic carbon (DOC) and suspended sediment concentrations in the water column (Brigham et al., 2009). Stream discharge is an important factor as it can be the dominant predictor for Hg flux in freshwater systems (Shanley et al., 2005).

Export of Hg out of catchments contaminated with Hg significantly exceeds export from uncontaminated systems where Hg naturally present in soil and atmospheric deposition are the only sources/pathways. Wang et al. (2004) recognised human induced erosion, urban discharges, materials used in agriculture, mining, and combustion and industrial discharges as the most important sources of Hg contamination in aquatic systems. In addition to various levels of contamination, Hg inputs to aquatic systems from contaminated sites vary greatly, as they depend on the site-specific hydro-meteorological conditions. For example, soil erosion in an area of small scale gold mining activities in the Tapajos River basin in the Brazilian Amazon resulted in the annual export of 1600 kg of Hg (Telmer et al., 2006). In the Thur River basin in France, which is heavily polluted by chlor-alkali industrial activity, the input of Hg is 70 $\mu\text{g}/\text{m}^2/\text{y}$, corresponding to 19 kg of Hg exported out of the catchment annually (Hissler and Probst, 2006). Estimated annual Hg fluxes from the Lot River in France, an area affected by coal-fired power plants, mining and metal processing, ranged from 35 to 530 kg/y for the past decade (Schafer et al., 2006).

Hydrology is probably the most important factor influencing the transport of Hg from catchments to downstream environments. It has been shown in many studies that Hg transport is highly episodic, associated with suspended solids during high flow events (e.g., Žagar et al., 2006; Kocman et al., 2011; Riscassi et al., 2011). During

these events (storms and flooding), not only is catchment soil erosion enhanced, but river bank erosion and disturbance of bed sediments remobilise previously deposited Hg, which significantly contributes to overall annual loads (Wang et al., 2004). For example, in the Carson River, Nevada, a single major flood event was responsible for the transport of ~1400 kg of Hg which was nearly 87% of the total flux over a 6-year time span (Carroll et al., 2004). During a two month period, over 75% of the total Hg flux in a stream draining an abandoned cinnabar mine site in California occurred in events lasting less than 5 days (Whyte and Kirchner, 2000). In one 200 minute period, the authors recorded 3.4 cm of rain, a 2.6-fold increase in streamflow, and an 82-fold increase in Hg flux (1.2–99 g/min). Similarly, during a large flood that lasted for 8 days, about 4700 kg of Hg was exported out of the Soča River catchment, draining the contaminated Idrija Hg-mine region in Slovenia (Horvat et al., 1999). This amount is approximately three times the annual Hg export from the catchment (1500 kg) under average hydrological conditions (Rajar et al., 2004). In uncontaminated systems, the Hg load in the particulate phase during high-flow conditions can be predicted based on turbidity and Hg concentrations, in conjunction with discharge measurements (Riscassi et al., 2011). Due to the known affinity of Hg with organic matter, especially in forested catchments, concentrations and fluxes of dissolved Hg are strongly related to DOC concentrations and quality (Dittman et al., 2010) which can be then used as a proxy measure to calculate Hg fluxes (Dittman et al., 2009).

Climate change is expected to alter some of the processes described above. For example, it could influence the magnitudes and frequency of flood-related fluxes of Hg, as well as its mobility and bioavailability, which could lead to changes in its uptake and accumulation in aquatic food webs. It is expected that higher frequencies and magnitudes of extreme hydro-meteorological events could increase inputs of Hg to aquatic systems through surface runoff, soil erosion and flooding.

Mercury releases from artisanal and small-scale gold mining (ASGM) are of particular interest in this Technical Report, and so the following section reviews specific knowledge about dispersal and fate of Hg from this activity in rivers. As in other rivers, Hg in rivers downstream from ASGM operations is predominantly associated with suspended particulate matter (Roulet et al., 2001; Telmer et al., 2006; Lacerda et al., 2012). Therefore the distribution and fate of inorganic or liquid elemental Hg released into rivers from ASGM is probably influenced primarily by the mobility, transport and deposition of Hg-containing sediment within the river system.

The Tapajós River, Brazil, one of the major Amazonian tributaries most affected by ASGM since the 1970s, has been relatively well studied compared to other ASGM-affected rivers around the world, and there is some evidence of comparatively high fish MeHg levels in the area of ASGM operations in this river (Berzas Nevado et al., 2010). However, a review of the literature concerning ASGM impacts showed that there remain many basic geochemical knowledge gaps

which limit understanding; even the role that ASGM plays as a source of riverine Hg contamination is under debate (Berzas Nevado et al., 2010). Early mass balance studies in the Tapajós and other Amazonian rivers concluded that mining and gold processing was responsible for extreme river and fish Hg contamination (e.g., Pfeiffer et al., 1993). However, the sampling integrity and data quality from these early studies have been questioned (Roulet et al., 2001). More recent studies (Roulet et al., 1999, 2001; Telmer et al., 2006) argued that the dominant cause of high Hg concentrations in Tapajós river water and fish was not directly the loss of Hg from ASGM operations. Instead, the disturbance and re-mobilisation of large quantities of Hg-enriched sediment and floodplain soil during mining was thought to be responsible. Similarly, Lacerda et al. (2012) concluded that the remobilisation of Hg naturally present in forest soils, during conversion of forest to other land uses, and not historic ASGM mining, was responsible for relatively high Hg levels in the Madeira River, western Amazon. Although the Amazon generally is not underlain by mercuriferous rocks, high organic matter detritus from the productive terrestrial vegetation may act as a Hg concentrator and promoter of methylation in the extensive areas of seasonally-inundated floodplain soils (Roulet et al., 2001; Wasserman et al., 2003).

Elsewhere, highly elevated concentrations of Hg in water and sediment have been reported within a few kilometres downstream of ASGM operations in Zimbabwe and Tanzania (van Straaten, 2000). The downstream distribution of this contamination was curtailed within a few kilometres by the presence of swamps, and iron oxyhydroxide-rich lateritic soils, which appeared to trap or adsorb dissolved and particulate Hg. The use of Hg in gold mining operations in several Asian countries has also been found to result in locally-contaminated aquatic ecosystems (Li et al., 2009), however the geographic dispersal of this pollution was not studied. The aquatic fate of Hg released from ASGM operations is therefore presently unclear; site- and ecosystem-specific factors including the form of Hg emitted, topography, drainage patterns, and soil organic matter, among others, may determine the ultimate extent and severity of aquatic ecosystem contamination from ASGM.

5.2.2.2 Lake pathways and fate

Empirical data and modelling studies indicate that there are many similarities in general between the important Hg pathways and fate in lakes and in the ocean, but with obvious differences in scale. Modelling of Hg dynamics in a series of four diverse lakes ranging from the world's largest, Lake Superior, to small lakes with a history of direct Hg inputs, showed that photoreduction of inorganic Hg in water followed by evasion of DGM to air, and burial in sediments, were the dominant inorganic Hg removal mechanisms in all of the lakes (Qureshi et al., 2009). Net demethylation in sediments and water outflow were the main pathways removing MeHg. Atmospheric deposition and water inflow from other lakes

and/or from the catchment were the dominant inorganic Hg inputs. These findings are generally corroborated by mass balance studies from a wide range of lakes, except that photodemethylation of MeHg in the upper water column has been shown to be an important loss process in many lakes as it is in the ocean (e.g., Sellers et al., 1996; Fitzgerald et al., 2005; Hammerschmidt et al., 2006; Jeremiason et al., 2009), with the rate dependent on organic content and water transparency. In Lakes Superior and Michigan, there was evidence for net MeHg production in the water column (Qureshi et al., 2009), similar to that reported recently in seawater (see Section 5.2.1.2). However, in general the main source of MeHg in lakes and rivers is diffusion from anoxic sediments including wetlands, where sulphate-reducing bacteria are believed to be primarily responsible (Gilmour et al., 1992; Hammerschmidt et al., 2006).

The influence of atmospheric deposition as a factor in MeHg levels in freshwater biota can be seen in the significant correlations between air-water Hg flux and MeHg levels in fish (Hammerschmidt and Fitzgerald, 2006c) and insects (Hammerschmidt and Fitzgerald, 2005) across broad geographical regions of North America. Such a relationship is also demonstrated by Hg isotope spike studies in mesocosms (Orihel et al., 2006) and in whole lake ecosystems (Harris et al., 2007). However, these findings should not be interpreted to demonstrate the immediate and direct uptake of Hg from atmospheric deposition into biota, because the Hg has to be first transported to the sites of methylation, which in freshwaters are dominantly sediments. The studies noted above may suggest that recently deposited Hg is more labile, but there is much evidence for methylation of *in situ* Hg. For example, there is isotopic evidence that MeHg in freshwater fish comes from the methylation of historically-deposited inorganic Hg in sediments and not directly from that in present-day deposition (Sherman and Blum, 2012). The geographic correlations between deposition and biotic Hg levels described above may therefore represent a first-order approximation reflecting the long-term accumulation of deposited Hg in sediments, its ongoing methylation, and subsequent uptake into lake food webs. When comparing biotic Hg between waterbodies, the varying inputs from watersheds, fringing and upstream wetlands, system dynamics and size, and the number of trophic levels in lake food webs, as well as the differences in net methylation potential driven by biogeochemical factors, are all important in determining the MeHg concentration in freshwater biota (Branfireun et al., 2005; Munthe et al., 2007).

The creation of artificial impoundments and reservoirs has been shown in many cases to rapidly induce significant increases of total Hg and MeHg in water and of MeHg in fish and other aquatic species (Lodenius et al., 1983; Bodaly et al., 1984; Paterson et al., 1998; Thérien and Morrison, 1999). Montgomery et al. (2000) showed that this effect did not occur in neighbouring natural lakes, thereby demonstrating that the effect was linked to reservoir formation. The decomposition

of submerged organic matter leading to anoxia in bottom waters, coupled with the microbially-driven methylation of the inorganic Hg present in flooded soils and vegetation, is believed to be the primary mechanism responsible in most instances (Hecky et al., 1991; Thérien and Morrison, 1999). After evaluating the biogeochemical controls on biotic Hg levels in the Three Gorges Dam in China, Wang and Zhang (2012) concluded that a cascading effect on multiple internal ecological, geochemical and physical processes was initiated by impoundment, most of which would lead to long-term increases in biotic Hg.

Downstream effects have also been reported following the release of Hg-contaminated reservoir waters (e.g., Bodaly et al., 1997). In some cases, water and biota Hg levels return to pre-impoundment values after 10 to 30 years (Montgomery et al., 2000; Bodaly et al., 2007). However, many reservoirs have organic-rich or wetland-fringed shorelines which experience wet-dry cycles as a result of regular water level drawdown. These ecosystems, especially those ringed with an extensive shallow littoral zone, are likely to be subject to long-term elevated MeHg concentrations in predatory fish and other high trophic level biota (Evers et al., 2007).

5.3 Anthropogenic impacts on aquatic mercury levels

5.3.1 Increases in seawater mercury

Examining the temporal trends of Hg in aquatic systems can potentially be a more robust and accurate measure of the degree of impact of anthropogenic activities in many cases than geographic comparisons. Spatial assessments of anthropogenic impacts on Hg levels can be confounded in some instances by varying underlying geogenic inputs or by fluctuating anthropogenic inputs in regions close to urban/industrial areas.

However, it is difficult to accurately gauge and interpret temporal change over years and decades in the concentration of Hg in seawater. It is possible to compare profile information collected at the same location and separated by significant periods of time; it is also important to keep in mind caveats about the effects of variability in water mass lateral and vertical transport. For example, as pointed out by Laurier et al. (2004), there can be measurable seasonal changes in Hg in the upper ocean water column concentrations that could be the result of deposition/mixing or alternatively result from changes in currents and ocean properties. Given intra-annual variation at any one site, the prospect of trying to discern and attribute causation to relatively small changes in Hg levels in the mixed layer over a few decades is challenging.

With that qualification in mind, two studies have reported evidence for opposing temporal trends in the Atlantic and Pacific Oceans over recent decades. Results suggest that Hg

levels have increased in the North Pacific Ocean between 200 and 1000 m (i.e., below the mixed layer) during the past few decades (Sunderland et al., 2009). Results from near Bermuda in the North Atlantic, on the other hand, suggest that there has been a substantial decrease in Hg concentration and change in the water column Hg profile (Mason and Gill, 2005). Other time-series data from the North Atlantic support this finding (Cossa et al., 1992). Studies on the Mediterranean Sea also indicate a decrease in water Hg concentrations between 1990 and 2004 (Coquery and Cossa, 1995; Cossa et al., 1997, 2009; Kotnik et al., 2007). Atmospheric trend studies from around the North Atlantic margin corroborate the declining trend observed in seawater (see Chapter 3 of this report). The trends in the available data are therefore consistent with the idea that Hg levels in the North Atlantic and Mediterranean were significantly perturbed during the past 30 to 50 years (at least) but are now recovering as industries in North America and Europe have gradually improved emissions control technologies (Pirrone et al., 2010; AMAP, 2011), whereas the North Pacific may be exhibiting Hg increases as a consequence of increasing atmospheric emissions from Asia.

5.3.2 Impacts on mercury in marine food webs

Owing to the inherent difficulties in consistently sampling and accurately interpreting seawater Hg time trends, a complementary approach is to determine the temporal trends of Hg in the tissues of aquatic biota, which integrate seawater Hg variations over relatively long periods of time (from months to decades depending on the type of tissue and species ecology; Outridge, 2005). As the Arctic is relatively remote from major urban/industrial regions of the world, the recent temporal trends of Hg in Arctic biota can indicate whether global background levels of Hg in food webs are changing. In the recent Hg assessment in the Arctic (AMAP, 2011), 83 time-series of Hg in marine, terrestrial and freshwater biota spanning the past two to three decades were statistically analysed. Although almost half of the time-series showed no significant trend, most of the increasing trends were in marine species (Rigét et al., 2011). Most of those occurred in northern Canada and Greenland, despite reductions in North American emissions in recent decades.

Reconstructing the long-term trends of Hg in animals back to pre-pollution times (conventionally set as pre-1800 AD) is a robust method of determining the impact that human activities have had on Hg levels in aquatic biota today. Animal hard tissues, such as teeth, hair, feathers and eggshells are useful long-term archives of biological Hg concentrations, because they tend to preserve well in dry, cold or low-oxygen environments such as polar regions or sedimentary deposits (Outridge, 2005). Also, studies with laboratory and wild animals indicate that Hg concentrations in mammalian hair and teeth, and in bird feathers, are correlated with the animals' intake of organic and inorganic

Hg and with their tissue concentrations of Hg (Born et al., 1991; Eide and Wesenberg, 1993; Eide et al., 1993; Bearhop et al., 2000; Outridge et al., 2000).

A review of the global literature revealed no long-term trend studies with freshwater animals. For marine animals, several studies are available from different regions of the northern hemisphere particularly from the Arctic. But because marine ecosystems are a key link to human Hg exposure via food, changes of Hg levels in marine animals can illuminate how human exposure from these sources may also have changed over the past few centuries. For the Arctic long-term data, hard tissue Hg concentrations from different species were converted to a percentage basis, whereby the highest annual median concentration in recent decades was set to 100%, and the 19th century and pre-industrial median concentrations were calculated as percentages of the recent values (Dietz et al., 2009). This approach was necessary because absolute concentrations in different species varied by three to four orders of magnitude both in the pre- and post-industrial period. Using percentages, the trends could be represented in a consistent and comparable manner across species. A consistent long-term pattern was found across a number of marine species (Figure 5.4). Mercury concentrations between the 13th to 16th centuries were relatively stable but increased on average by over 12-fold during the 20th century. The pre-industrial hard tissues contained on average 7.6% (range 5.6–26%) of the maximum annual average Hg levels in the same species in the same areas during recent decades. This finding means that, on average, 92% (range 74–94%) of the present-day Hg in Arctic marine wildlife is likely to be of anthropogenic origin. A similar finding (96% anthropogenic) was reported by a more recent study using polar bear hair from northwest Greenland (Dietz et al., 2011).

Similar findings to those from the Arctic were reported for a 700 year sequence of seabird eggshells from an island in the South China Sea (Xu et al., 2011). Between 1800 and 2000, eggshell Hg concentrations increased steadily, with a particularly rapid increase after 1970, so that average Hg levels over the past two hundred years (15.1 ng/g, $n = 9$) were more than four times higher than pre-industrial levels (mean 3.45 ng/g, $n = 53$). Recent (2008) concentrations were 36.7 ng/g dw ($n = 4$, range 33.8–41.8 ng/g), about ten times higher than the pre-1800 levels. This is equivalent to an anthropogenic Hg contribution of 91% in modern eggshells, using the Dietz et al. (2009) calculation method. For the Antarctic, a 2000 year record of Hg in seal hairs was retrieved from a lake sediment core (Sun et al., 2006). The Hg concentrations (ca. 1 µg/g) in the pre-industrial period were on average about 60% of those in the uppermost sediment layer (1.7 µg/g), which would suggest an anthropogenic contribution of about 40% of total Hg in modern elephant seal hair. This contribution is less than half of that in marine biota in the Arctic Ocean and South China Sea, and is in accordance with lower anthropogenic Hg emissions and lower atmospheric Hg concentrations in the southern hemisphere

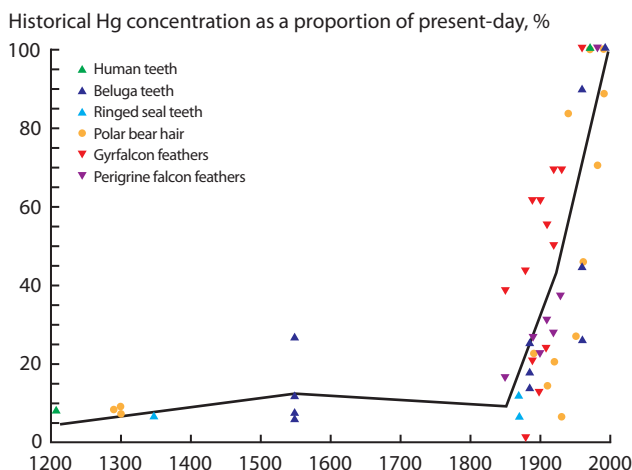


Figure 5.4. Historical trends in mercury concentrations in the hard tissues of Arctic animals and humans, expressed as a percentage of modern maximum annual average concentrations. Source: adapted from AMAP (2011) and Dietz et al. (2009). Most points plotted represent mean values of multiple samples; for beluga and seal teeth, these are presented for different age classes. Original data sources: beluga teeth (Outridge et al., 2002, 2005, 2009); ringed seal teeth (Outridge et al., 2009); human teeth (Eide et al., 1993; Tvinnereim et al., 2000); polar bear hair (Wheatley and Wheatley, 1988; Dietz et al., 2006a); and gyrfalcon and peregrine falcon feathers (Dietz et al., 2006b). Regions covered by these datasets include parts of the Canadian Arctic, Greenland Arctic, and northern Norway).

compared to the northern hemisphere (see Chapters 2 and 3 of this report).

Museum specimens of seabird feathers were used to demonstrate two-fold MeHg increases since 1880 in black-footed albatross in the North Pacific Ocean (Vo et al., 2011), and three- to six-fold increases since 1885–1900 in shearwaters and petrels in the subtropical North Atlantic (Monteiro and Furness, 1997). These increases are smaller than those from the longer-term datasets from the Arctic and the South China Sea, and may be because the datasets started late in the 19th century after industrialisation had already had an impact on biotic Hg levels.

The above conclusions assume that the long-term increases in Hg concentrations in marine biota occurred solely as a result of increased inputs of Hg from pollution sources, and that potentially confounding factors such as coincident changes in the cryosphere, biogeochemical processes (such as changes in methylation rate or Hg reduction rate), diet, food-web structure or other ecological factors (see AMAP, 2011, Chapters 4 and 5) did not significantly affect the Hg trends. The possible effect of many of these other processes is difficult to assess, first because of a lack of long-term data concerning how these processes have changed in the specific areas in which the long-term Hg studies were conducted, and second because of uncertainty as to how and to what degree these types of change might affect Hg levels in biota. However, by inferring possible dietary behaviour changes using stable isotopes of carbon and nitrogen, several studies (Outridge et al., 2002, 2009; Dietz et al., 2011; Vo et al., 2011) found no evidence that such changes had interfered with interpretation of the temporal Hg trend data (see also Dietz et al., 2009).

5.3.3 Timing of long-term biotic increases

The timing of long-term increases of Hg in biota can be informative about the likely continental sources of the Hg pollution which gave rise to these increases. As no data were available for the Arctic from the period between the 16th century and about 1850, it is not possible to precisely identify the onset of the steep industrial era increase. However, based on the shape of the curve it seems plausible that, on average, Hg in Arctic marine ecosystems started to increase somewhere between 1850 and 1900, with a clear acceleration in the rate of increase after 1900 (see Figure 5.4).

The same conclusions were drawn by individual studies with sufficient time coverage in the late 19th and early 20th centuries. After assessing two adjacent and complementary Arctic datasets, that is, Hg in the teeth of beluga in the Beaufort Sea and of ringed seal in Amundsen Gulf, Canada, Outridge et al. (2009) concluded that Hg levels in marine biota in this region were stable from pre-industrial times up to at least the 1890s, with substantial increases occurring between then and the 1990s. Much of the increase occurred prior to 1960. The feathers of seabirds (guillemot species in the Baltic Sea; shearwaters and petrels in the eastern subtropical North Atlantic) displayed marked Hg increases only after the 1890s (Appelquist et al., 1985; Monteiro and Furness, 1997). In the South China Sea, increases of Hg in seabird eggshells appear to have started about 1825 to 1850, earlier than in the Arctic and North Atlantic Oceans (Xu et al., 2011). But this may be an artefact of the scarcity of pre-1850 samples in the other datasets. Taken together, there is substantial empirical evidence of large anthropogenic increases of Hg in pelagic ocean food webs since at least the late 19th century and possibly as early as the 1820s, which coincide with the rise of industrialisation in Europe and North America, and of recent rapid increases in the South China Sea which coincide with industrialisation in Asia.

5.3.4 The time-lag in aquatic ecosystem response

One important conclusion from the air-ocean modelling work is that, on average, the global oceans are likely to have not yet reached equilibrium with present-day atmospheric Hg levels (Sunderland and Mason, 2007; Selin et al., 2010). This response time-lag is due to several factors. First, the average residence time for Hg in the global upper oceans is significantly longer (20–30 years) than that in the global atmosphere (0.8–2 years), and so removal of Hg added to the oceans takes substantially longer than in the atmosphere (Sunderland and Mason, 2007). Second, the global ocean contains a relatively large mass of natural (geogenic) Hg that has been augmented to varying degrees by anthropogenic inputs (see Figure 5.2). For example, of the ~135 000 t of Hg estimated to be presently in subsurface ocean water, ca.

100 000 t is natural, that is, an equivalent amount was present in the oceans prior to the Industrial Era (Sunderland and Mason, 2007). Thus, changes in atmospheric deposition rates will not proportionately alter seawater Hg levels; responses in seawater Hg will be comparatively more muted and will occur more slowly than the changes in emissions. Finally, vertical transport of Hg from this large subsurface reservoir to surface waters returns a substantial amount of Hg back to the biologically productive mixed layer each year, approximately 2500 t/y (38%) out of the ~6600 t/y added to surface waters by all processes (see Figure 5.2). The consensus view among marine Hg scientists is that this unavoidable time-lag in ocean response to changes in atmospheric Hg means that average Hg concentrations in seawater, and in marine biota, are likely to increase slowly for periods ranging from decades to several centuries, even if there is no further increase in atmospheric Hg levels (Sunderland and Mason, 2007; Selin et al., 2010; Mason et al., 2012).

The effect of future changes in anthropogenic emissions on seawater and marine biota Hg levels is also likely to be partly buffered by the significant amount of historically-deposited Hg which is re-emitted from surface soils and the oceans. As discussed in Chapter 2 of this report, these re-emissions act to maintain atmospheric Hg concentrations at higher levels than current anthropogenic emissions would otherwise dictate. Because atmospheric Hg deposition is the major input pathway for Hg entering the world's oceans, re-emissions to air also play an important role in determining current and future Hg levels in seawater. The effects of growing emissions from Asia and other developing regions on seawater Hg levels therefore will exacerbate the impacts of historical pollution from Europe, Russia and North America which is being continually recycled between air, land and oceans. The impacts of these historical emissions are still being fully realised due to the ocean circulation and biogeochemical processes discussed above.

Regional differences in future seawater and marine biota Hg trends are expected, with the time taken to reach equilibrium with the atmosphere predicted to differ as a result of varying circulation patterns, water residence times, and proximity to regions of industrial activity (Sunderland and Mason, 2007; Selin et al., 2010). For example, the time to steady state of the North Atlantic Ocean above latitude 55° N is estimated at 50–600 years, compared to 500–700 years in the North Pacific and 700–1000 years in surface waters of the Antarctic (Sunderland and Mason, 2007). The response of smaller ocean basins and of surface waters will be naturally faster: the Arctic Ocean is estimated to take only 35 years to fully manifest changes in atmospheric inputs (AMAP, 2011), while the surface Mediterranean responds in 10–50 years and the surface Atlantic in 10–30 years (Sunderland and Mason, 2007).

The response of freshwater ecosystems to changes in atmospheric Hg deposition is thought to be more complex than oceans but may be generally more rapid because of

smaller volumes, shorter Hg residence times and more rapid mixing (see Qureshi et al., 2009). However, while increases or decreases in current atmospheric loadings often yield an immediate response in Hg levels in freshwater biota, the timing and magnitude of the response depends on system-specific factors and the form of Hg loaded (Munthe et al., 2007). Generally, lakes, reservoirs and rivers that have catchments and sediments loaded with historically deposited Hg, or that receive a larger fraction of their atmospheric inputs from the hemispheric 'background' (which in turn is influenced by long-range transported GEM), or that have larger catchment to water surface area ratios, are predicted to show more muted and slower responses to emissions reductions than systems with smaller catchment to surface area ratios, or which are more heavily influenced by local sources (Grigal, 2002; Munthe et al., 2007; Knightes et al., 2009; Selin et al., 2010; Wang and Zhang, 2012; Tang et al., 2013). Global re-emissions also impact regional and local freshwater ecosystems through their buffering effect on hemispheric atmospheric Hg levels. Re-emissions of current and historically-deposited anthropogenic Hg, and its global distribution in air, means that even regions which have made substantial cuts in local Hg emissions are likely to continue to receive above-background loadings in deposition until global surface ocean and soil Hg levels return to steady-state conditions under stable atmospheric concentrations, a process which may occur on time-scales of centuries to millennia following substantive emissions reductions (Sunderland and Mason, 2007; Selin et al., 2010; Mason et al., 2012). Present atmospheric deposition rates in most regions of North America, largely reflecting the hemispheric GEM concentrations, are continuing to load the catchments of lakes and rivers with Hg despite recent major reductions in emissions and deposition on this continent (Selin et al., 2010).

Apart from re-emissions to air, historical anthropogenic and natural Hg deposition can impact present freshwater Hg levels through the loading of Hg into catchment soils, so that current Hg deposition and stream fluxes are to some extent disconnected. Munthe and Hultberg (2004) demonstrated that Hg fluxes in stream runoff were independent of current rates of atmospheric wet deposition. After completely covering a stream's catchment with an impermeable roof and thereby reducing contemporary wet inputs to zero, stream export rates of total and MeHg were unchanged over the following ten years. Instead, the ongoing release of historical Hg in catchment soils, probably at rates determined by the mineralisation of soil organic matter, controlled stream Hg flux (Munthe and Hultberg, 2004). Similarly, catchment soil retention and slow release of Hg is believed to explain the delayed declines in fluxes to lake sediments following emissions reductions from nearby point sources (e.g., Nriagu et al., 1998; Outridge et al., 2011). Harris et al. (2007) also demonstrated that Hg isotopes added to a lake's catchment were released to the lake at a very slow rate (<1% per year), probably because of binding to soil organic matter, whereas isotope added to lake water began

to be assimilated by the lake food web within a year. They predicted that while rapid declines in fish MeHg levels would follow significant reductions in atmospheric Hg deposition, a complete recovery would be delayed by the gradual export of Hg stored in their catchments. In contrast, a large database on Hg in freshwater fish in 73 Ontario lakes showed no recent declines in fish Hg levels in response to declining atmospheric Hg deposition (Tang et al., 2013).

Storage of historic inorganic Hg in lake sediments can have a similar buffering effect on fish Hg levels. Using variations in Hg stable isotope ratios in precipitation, sediments and fish from lakes affected by emissions from a coal-fired power plant, Sherman and Bum (2012) showed that current deposited Hg was not preferentially accumulated in the fish. Instead, historically-deposited inorganic Hg that had accumulated in lake sediments was the source of fish MeHg. This finding is consistent with the general observation that sediments are the main sources of MeHg in lake waters, and that sediment production of MeHg is often dependent on the inorganic Hg supply (Hammerschmidt et al., 2006; Fitzgerald and Lamborg, 2007). Sherman and Blum (2012) concluded that, depending on a lake's physical and biogeochemical processes, decreased atmospheric loading would not necessarily lead to immediate reductions in fish MeHg, and that full recovery to baseline fish Hg levels might take decades to centuries. Although aquatic biota Hg levels are generally correlated geographically with atmospheric deposition rates (e.g., Hammerschmidt and Fitzgerald, 2005, 2006c), this relationship should not be interpreted as evidence for a rapid response of biotic Hg to future changes in atmospheric deposition. Instead, it is likely to reflect geographical variations in the long-term accumulation of deposited Hg in sediments, its continuing methylation, gradual diffusion into water, and eventual uptake into lake food webs. This process also explains why Harris et al. (2007) found a continuing effect on fish Hg levels for several years after adding an isotope spike to lake waters; the isotope may have been initially carried into the sediments where it was added to other inorganic Hg and eventually methylated, prior to its uptake by the lake food web.

Climate warming has the potential to profoundly alter the Hg cycle in the biosphere (Grimalt et al., 2010; Stern et al., 2012). One consequence may be to further complicate the relationship between emissions reductions and Hg levels in aquatic ecosystems (Outridge et al., 2008; Wang and Zhang, 2012). For example, higher temperatures may increase rates of organic productivity, and rates of bacterial activity, in aquatic ecosystems possibly leading to faster conversion of inorganic Hg to MeHg. Precipitation patterns, rates and timing may change the amounts and timing of Hg delivery. Thawing of frozen northern peatlands may release significant amounts of Hg and organic matter accumulated during the Holocene into adjacent water bodies (Rydberg et al., 2010) and the Arctic Ocean (Outridge et al., 2008) with subsequent effects on the rate of Hg methylation.

5.4 Key findings on aquatic pathways, transport and fate

1. Atmospheric deposition is the major pathway for Hg to enter most aquatic systems, both marine and freshwater. The annual rate of deposition of Hg to oceans and freshwaters has increased about two- to three-fold on average since the Industrial Revolution.
2. Delivery of Hg from terrestrial to freshwater systems is mainly associated with soil erosion and consequent sediment transport, and depends on the characteristics of the catchment, especially its size and topography, land cover, land use, and site-specific hydro-meteorological conditions.
3. In rivers, hydrology is by far the most important factor influencing the transport of Hg from catchments to downstream environments. Most of the annual transport is associated with Hg bound to suspended solids during high flow events (storms and flooding).
4. Natural processes occurring within aquatic ecosystems are responsible for converting the less toxic inorganic and elemental Hg forms emitted from anthropogenic and natural sources into the much more toxic form, MeHg. Methyl mercury accumulates and biomagnifies to relatively high levels in the upper trophic levels of marine and freshwater food webs, thus posing a risk to wildlife and humans.
5. The Hg cycle may be strongly affected by changes to the organic carbon cycle, particularly as it pertains to MeHg production in concert with organic matter mineralisation in oceans and sediments. This effect may interact with climate change, especially in aquatic ecosystems experiencing an increase in organic matter productivity or the restriction of oxygen supply due to increased light, nutrient supply or stratification.
6. Studies of the long-term trends of Hg in high trophic level marine animals (seals, seabirds, polar bear, beluga) show that the current biological Hg concentrations are on average about 12-fold higher than in pre-industrial times (i.e., prior to 1800 AD), even in remote regions such as the Arctic. The timing of the initial Hg increases in marine biota roughly coincided with the acceleration of western industrialisation in the late 19th and early 20th centuries.
7. Because of the slow natural rate of removal of Hg from the ocean, seawater contains a large amount of relatively old natural Hg, which has been augmented to varying degrees by anthropogenic Hg pollution. Surface waters to 100 m depth contain about twice as much Hg as a century ago, whereas intermediate and deep waters have about 10–25% more Hg on average, the difference being due to the delayed transport of surface-deposited Hg into deeper water by slow-moving ocean currents.
8. Seawater Hg concentrations are slow to respond to changes in Hg inputs (both increasing and decreasing) because of the slow rate of vertical and horizontal water exchange in oceans, the high proportion of natural Hg present, and the upwelling of some of the Hg in intermediate waters back to the surface.
9. The time-lag in ocean response to changes in atmospheric Hg means that average Hg concentrations in seawater, and in marine biota, are likely to increase slowly for periods ranging from decades to several centuries, even if there is no further increase in global atmospheric Hg levels.
10. Similarly, even for freshwater ecosystems in regions where reductions in atmospheric Hg concentrations have occurred because of recent emissions controls, the current atmospheric loadings continue to load catchment soils with anthropogenic Hg. This Hg is likely to continue to slowly leach out into lakes and rivers, and into freshwater food webs, over the following centuries to millennia.
11. The effect of emissions reductions on Hg in freshwater biota may vary between different types of lakes and rivers. Some areas, such as small temperate lakes and rivers strongly impacted by regional or local anthropogenic sources, may experience a rapid reduction in upper trophic level Hg concentrations. However, others more influenced by the global atmospheric background, or which have heavy loadings of historical anthropogenic Hg in catchment soils or sediments, are likely to recover over much longer time-frames.
12. Because historical Hg emissions continue to circulate in the world's oceans, further increases in atmospheric emissions in future will have long-term consequences for Hg levels in the world's commercial fisheries, and for Hg exposure among indigenous, subsistence and recreational consumers of marine and freshwater foods.
13. Expanded, standardised and integrated monitoring of Hg levels, particularly in the world's oceans, is essential to improve understanding of the impacts of human activities and future changes in emissions on aquatic Hg levels and the resultant human exposure. Integrated monitoring of the Hg cycle, including methylation/demethylation rates, in water, air, sediments and biota at key global locations is recommended. Monitoring should include ecosystems and food webs that are particularly sensitive to Hg loading, for maximum protection of ecological and human health.

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Annex 1: Method used to estimate 2010 mercury emissions to air from main 'by-product' emission sectors and the chlor-alkali industry, including an example calculation

The 2010 inventory estimates for most sectors are based on a three step approach:

Step 1 involves compiling **activity data** – statistical data concerning consumption of fuels and raw materials and production of products that are relevant to calculation of Hg emissions from energy/industrial sectors; and data on Hg consumption in intentional use sectors that allows estimates to be made of Hg emissions from waste streams, etc.

Step 2 involves the compilation of 'emission factors' that can be applied to the activity data to derive estimates of **unabated/uncontrolled emissions to air** – a typical example might be the fraction of Hg in coal that is released to the atmosphere when the coal is burned (prior to any technological measures to reduce emissions of air pollutants). Important to note here is that these are **unabated emission factors (UEF)** and therefore differ from the **(abated) emission factors (AEF)** that are commonly reported/used to produce end-of-pipe emissions estimates. These UEFs can be considered as being similar to the **input factors** applied in the UNEP Toolkit approach, but differ in that – in most cases – they relate to the emissions/inputs only to air as opposed to the total release of Hg to all media that are obtained from the UNEP Toolkit input factors. To take this comparison a stage further, the UEFs employed in this work are approximately comparable to the UNEP Toolkit input factors multiplied by their respective **distribution factor (DF)** for the proportion of the input released to air; however, it should be noted that UNEP Toolkit factors were not always adopted, and information developed during the current work is being used in updating of the UNEP Toolkit factors. The UEFs, when applied to the activity data from Step 1 yield estimates of unabated (uncontrolled) emissions to air from the activity concerned.

Step 3 involves an attempt to represent the 'technology' that is applied in the respective sectors in different countries to control (reduce) Hg emissions to the air – typically through the application of **air pollution control devices (APCDs)**. These technologies are characterised by their effectiveness (Hg emissions reduction efficiency) and their degree of application. In Step 3 it is necessary to recognise that available information – based on a relatively few (but increasing number of) measurements made at individual plants in certain (mainly developed) countries – demonstrates that effectiveness of APCDs is very variable and depends on plant operating conditions, specific characteristics of fuel and raw materials, etc. In addition, the general scarcity of relevant information on both the effectiveness of APCDs and their degree of application in various sectors/countries means that assumptions need to be made. First, on the basis of available information, technologies have been grouped according to their general degree of

effectiveness at reducing Hg emissions; and according to their degree of use (e.g., commonly applied APCD configurations). Second, countries have been assigned – on the basis of an assumed general level of technological implementation of APCDs – into five groupings (see Section 2.2.3.1). Information on the effectiveness and degree of implementation of APCDs in those countries for which information is available (derived from published literature, grey literature and application of the UNEP Toolkit, etc.) has then been used to characterise the **technological profile** for the country-group to which the country belongs. The resulting technology profile – or a specific national profile for countries where such detailed data are available – has been applied to the unabated/uncontrolled emissions estimates resulting from Step 2 to produce abated (controlled) emission estimates for all countries/sectors for which activity data are available from Step 1. These estimates constitute the global inventory of Hg emissions to air from the represented anthropogenic sectors.

As described, the applied methodology relies on statistical data and assumptions concerning emission factors and technological profiles, etc., that are based on often very limited available information. However, this methodology is designed to improve on previous approaches employed to derive global emissions inventories and to compile relevant statistics and other information in a manner that allows it to be transparent, readily updatable as new information becomes available, and potentially useful for other purposes (such as emission scenario development).

A full description of the emission factors and technology profiles applied in this work, is given in Annex 6, which also contains extensive notes explaining their basis, and comparisons with emission factors used in other studies (including the UNEP Toolkit and 2005 inventory).

The documentation procedures described above and transparency regarding assumptions made, etc., is intended to allow for future updates of the inventory for individual countries and sectors as more detailed information becomes available.

Example calculation

The following example shows the calculations applied to estimate Hg emissions from cement production in China. Under the regionalisation approach described in Section 2.2.3.1, China is in the Group 3 countries with respect to characterisation of applied technology.

According to the US Geological Survey, China produced 1629 000 kt of cement in 2009 (see Annex 5).

The (country-specific) UEF applied to cement production in China is 0.087 g/t cement (see Annex 6). About 80% of cement production in China is based on coal; emissions from the fuels are not included in this UEF (these are accounted under the SC-IND – stationary fossil fuel combustion in industrial uses – sector). This UEF is the same as that employed as the generic UEF for cement production resulting from Hg in raw materials (limestone) in the absence of co-incineration of waste. The resulting unabated emission estimate for this sector in China is therefore 141.723 tonnes [= 1629000000 × 0.087 grams].

In Group 3 countries the technology profile applied for cement production (see Annex 6) implies that ~20% of the emissions from cement production in China are not subject to any emission control, and 80% are subject to (basic particulate matter) emission controls that reduce Hg emissions by about 25%. On the basis of these assumptions, the associated (abated) Hg emissions would be reduced from around 142 to around 113 tonnes, with some 28.3 [= 141.723 × 0.8 × 0.25] tonnes of Hg being captured by the APCDs.

However, national information provided by China indicated that a more accurate representation of the abatement technology applied in the Chinese cement sector is that all Chinese cement plants are fitted with dust removal systems (about 80% equipped with fabric filters and about 20–40% with electrostatic precipitators) with an effective Hg capture of 40%. Applying this new profile, about 56.7 (141.723 × 1 × 0.4) tonnes of Hg are removed by the APCDs, resulting in an estimated emission to air from the cement sector in China of some 85 tonnes.

To estimate an uncertainty range for this estimate, these calculations were repeated using low and high values of 1140 300 and 2117 700 kt, respectively for the activity data (see Section 2.2.7, Table 2.3; ± 30% applied to activity data from sources other than International Energy Agency (IEA) or official national data). In addition, for the low range estimate the UEF was reduced from 0.087 to 0.046 g/t [= 0.087 minus half the difference between this value and the tabulated low UEF of 0.005 g/t]; and for the high range estimate a UEF of 0.238 g/t was applied [= 0.087 plus half the difference between this value and the tabulated high UEF of 0.389 g/t] (see Annex 6 and Section 2.2.7, Table 2.3). No adjustments were made to account for uncertainties in the applied technology profile (i.e., the reduction in emissions due to abatement technology). The resulting range of (abated) estimates is therefore 31.4 [= 1140 300 000 × 0.046 × 0.000 001 × 0.6] to 302 [= 2117 700 × 0.389 × 0.000 001 × 0.6] tonnes, where the first term is the activity in tonnes, the second term is the UEF in g/t, the third term is the factor to convert the emission estimate from grams to tonnes, and the fourth term is 1 minus the 40% reduction due to abatement).

Annex 2: Method used to estimate 2010 mercury emissions to air from artisanal and small-scale gold mining, including an example calculation

The 2010 inventory estimate of Hg emissions from artisanal and small-scale gold mining (ASGM) is based on an understanding of ASGM, direct field evidence, a wide variety of secondary information sources, analysis of official trade data, and extrapolation of these various data. There is now reasonably good information about where ASGM is occurring. Main information sources used include: decades of archives from the Northern Miner – a mining trade magazine that regularly reports the ‘presence of artisans’; reports and conference materials from the World Bank; reports and follow-up from the UNDP/GEF/UNIDO Global Mercury Project (GMP); reports from currently operating GEF-UNIDO projects, reports from other intervention programmes such as the Swiss Agency for Development and Cooperation (SDC), the Canadian International Development Agency (CIDA), the World Wildlife Fund (WWF), etc.; reports and abstracts from the International Conferences on Mercury as a Global Pollutant (ICMGP) up to 2011 (10 congresses); reports from the MMSD (2002); articles published in the peer reviewed literature; and new field reports from field programmes and intervention programmes that are directly involved with government and people employed in the ASGM economy – miners and gold and Hg merchants.

Based on information on practices used in different countries, it is estimated that, on average 45% of Hg used in ASGM is emitted to the atmosphere with the remainder released to land and water. In regions where concentrate amalgamation is practiced, although the absolute amount of Hg used is typically lower than in other practices such as whole ore amalgamation, 75% of the Hg used is emitted to the atmosphere, whereas localities that practice whole ore amalgamation use much more Hg per unit gold produced, but release a much larger portion of the Hg to aquatic and terrestrial systems, some of which is re-emitted to the atmosphere at later times. Estimates from Australia and Canada (Winch et al., 2008; Parsons et al., 2011) suggest that a large proportion of the Hg used in historical gold mining operations in the 1800s has been remobilised.

The total amount of Hg used in ASGM applications (see Table A2.1) can be estimated using four main approaches: (1) direct measurements – using a balance to directly weigh amounts of Hg used; (2) applying a mercury/gold (Hg:Au) ratio to estimates of gold production based on the type of process used (whole ore amalgamation or concentrate amalgamation or the use of emission controls like retorts, etc.); the estimates of gold production can come from the number of miners actively mining and their average yearly gold production, or from other sources such as government reports on gold production or mining populations; (3) interviewing miners

and gold merchants who buy or sell Hg; (4) using official trade data. The first three approaches involve directly working with miners and gold merchants. This information can then be used to constrain, through triangulation a more robust estimate of the amount of Hg used and released to the environment and the amount emitted to the atmosphere.

The most reliable results are rooted in field work and relationships with stakeholders. In order to do this, personnel making the estimation must be capable of understanding mining practices and gold trade. Mercury use practices and gold production are key pieces of information. Determining these requires combining information from field data, miners, mining communities, buyers, traders, geological surveys, ministries responsible for mining, mining commissions, the private sector, exploration company press releases, industry magazines, environmental ministries, and others. This information must be analysed to understand what is reasonable based on expert knowledge of geology, mining, ASGM practices, mining communities, and socio-economics. The results of the analysis should be discussed with stakeholders such as miners, concession holders, local governments, and national governments to obtain their input and help constrain the analysis.

The fundamental questions that need to be answered in order to make an annual estimate of Hg use and emissions are:

1. Is mercury used?
2. What are the practices in use? (consider: Whole ore amalgamation? Concentrate amalgamation? Mercury activation?)
3. How much mercury is used per unit gold? – grams of mercury lost per grams of gold produced? (consider: Do miners discard used mercury? Do the miners use retorts or recycle mercury?)
4. How much gold do miners produce per year?
5. What is the total number of miners?

The format of the questions needs to be adapted to local conditions. For example, it is often necessary to convert the amount of gold produced per day into an annual number by taking into account further information about work habits throughout the year – for example, how work varies seasonally.

The quality of estimates varies across countries and can be grouped into four main classes: class 1 = presence/absence, no quantitative information, error can be greater than $\pm 100\%$ (25 countries); class 2 = some indication of quantity of Hg used, estimated average error $\pm 75\%$ (20 countries); class 3 = quantitative data but not significantly updated within past five years, error $\pm 50\%$ (17 countries); class 4 = recent quantitative data; error $\pm 30\%$.

Example calculation

The following example describes the method used to make a class 4 estimate of Hg releases from ASGM in Burkina Faso over a two-year time frame (2011/2012).

The Director of the Ministry of Mines, Geology, and Quarries estimates 600 000 adults living on 221 ASGM sites that are registered as ASGM exploitation permits, and plotted on a cadastral map. At least the same number inhabits and operates on unregistered land. Meetings were held before and again after field visits with: miners in the field, government agencies, miners associations (formal + informal), gold traders and Hg traders. The results are as follows: All ASGM activities use Hg. This began around year 2000. Whole ore amalgamation is never done. Concentrate amalgamation is done. Mercury activation is not practiced. Miners do not throw away dirty Hg. Miners never use retorts or recycle Hg in other ways – amalgam is burned using an open flame. The amount of Hg used per unit gold produced is on average 1.3 parts mercury to 1 part gold (i.e., a mercury to gold ratio of 1.3:1). This accounts for the Hg that ends up in the amalgam (1 part) and the Hg that is lost during processing to the tailings (0.3 parts). All Hg used is released to the environment, with 75% (that in the amalgam 1/1.33) directly emitted to the atmosphere during amalgam burning and the residual (0.3 parts) lost to the tailings. In Burkina Faso, it is likely that the amount lost to the tailings is re-emitted to the atmosphere on a relatively short time scale of one to several years as the tailings are accumulated in above ground piles and later reprocessed.

200 000 of the 600 000 official ASGM population (1 in 3) are estimated to be active miners. They produce 20 to 30 tonnes of gold per year (~25). This is reasonable considering the known geology (abundance of gold-bearing formations of sufficient grade throughout the country), a processing lens (gold production per miner using the observed processing techniques), and through a socio-economic lens based on the cost of living at ASGM localities. This estimate was discussed with the gold buyers and site owners and the Ministry of Mines and was found to be reasonable by these groups. The amount of Hg used and emitted to the atmosphere is thereby determined as follows: 25 tonnes of gold are produced annually; all of it is amalgamated using 32.5 tonnes of Hg per annum. All amalgam is burned openly thereby emitting 25 tonnes of Hg directly to the atmosphere with the remaining 7.5 tonnes being released to the land and water in the waste stream (tailings). The Hg contained in tailings is likely to also be emitted to the atmosphere within a decade.

It may be helpful to briefly describe some of the other supporting information that is typically used in determining the annual gold production and Hg use. In Burkina Faso, ASGM miners typically operate in 5–10 person partnerships consisting of diggers, haulers, crushers, millers, and amalgamators. Women also work in groups, but typically only haul, crush and process tailings. Relatively small amounts

of Hg are used (1.3 units Hg for 1 unit gold) and awareness of the dangers of Hg is low and therefore retorts are not currently used for economic or health reasons, indicating that no Hg is recycled. Ore grades are high (often 10–50 g/t) but traditional mining is inefficient (15–50% recovery). On average, miners yield half a gram per day for about 270 days per year, equating to about 135g/miner/year. They receive 70–80% of the international price when selling to the local buyer who has a relationship to the land holder of the site. Using 80% of a gold price of USD 1500/oz (USD 48.24/g), each miner makes about USD 5209/year or 434/month. However, costs for miners are high and estimated to be USD 200–500/month and consist of costs for processing (milling and Hg), food, shelter, transport, and family including off-site family.

The estimate for Burkina Faso serves also to make some useful points for emissions estimations in general. The previous (2005 inventory) emission estimate for Burkina Faso was about 3 t Hg/y based on MMSD (Mining, Minerals and Sustainable Development) work in 2001 and presence/absence data from mining trade magazines and newspaper reports in 2008. The current estimate of 32.5 t Hg/y represents a ten-fold increase. This increase is not a result of increased use but rather of better reporting. This serves to illustrate the potential magnitude and the expected direction of uncertainties in countries that are currently estimated to be using a conservative minimum amount of Hg (0.3 t Hg/y) based on a simple presence/absence criteria or countries for which estimates are becoming dated. In other words, it is likely that the estimated quantity of Hg being used annually in ASGM globally will rise as better data become available through better inventory work.

In conclusion, robust estimations of Hg emissions from ASGM remain sparse and the global estimate needs further development. The current estimate of roughly 1600 tonnes total Hg use per year $\pm 50\%$ is a conservative minimum assigning small numbers and large errors to countries where little information exists. The estimate has risen since the last estimate published in 2008 primarily due to improved reporting rather than increased use, albeit the latter is also likely to have occurred due to the increase in the price of gold. The estimation of Hg use in ASGM requires trained experts that can reliably assess the informal gold economy and its Hg use, as well as reliably upscale field observations to national levels. Aside from technical geo-scientific expertise, this frequently requires establishing adequate relationships with the numerous stakeholders. Relevant and updated information about Hg use in ASGM is being compiled regularly in the online mercury-watch database (www.mercurywatch.org). Significant knowledge gaps remain but these can (and are) being addressed with increasing reliability.

Table A2.1. Mercury consumption in artisanal and small-scale gold mining and calculation of associated emissions.

Country	Quality of data ^a	ASGM Hg use, t			Percentage of total Hg applied to concentrate amalgamation	Percentage of total Hg applied to whole ore amalgamation	Emission Factor ^b	Year of most recent data	Mean air emission, t
		min	mean	max					
Total		910.0	1607.8	2305.6					726.771
Angola	1	0.1	0.3	0.5	100	0	0.75	2009	0.225
Benin	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Bolivia	4	84.0	120.0	156.0	25	75	0.38	2012	45.000
Botswana	2	0.2	0.8	1.4	50	50	0.50	2010	0.400
Brazil	4	31.5	45.0	58.5	50	50	0.50	2007	22.500
Burkina Faso	4	24.6	35.1	45.6	100	0	0.75	2011	26.325
Burundi	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Cambodia	3	3.8	7.5	11.3	50	50	0.50	2006	3.750
Cameroon	2	0.4	1.5	2.6	100	0	0.75	2011	1.125
Central African Republic	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Chad	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Chile	2	1.0	4.0	7.0	50	50	0.50	2009	2.000
China	3	222.3	444.5	666.8	25	75	0.38	2004	166.688
Colombia	3	90.0	180.0	270.0	17	83	0.33	2012	60.000
Congo	2	0.4	1.5	2.6	100	0	0.75	2010	1.125
Costa Rica	1	0.1	0.3	0.5	50	50	0.50	1998	0.150
Dominican Republic	1	0.1	0.3	0.5	100	0	0.75	1997	0.225
Democratic Republic of Congo	2	3.8	15.0	26.3	100	0	0.75	2010	11.250
Ecuador	3	25.0	50.0	75.0	20	80	0.35	2007	17.500
El Salvador	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Equatorial Guinea	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Ethiopia	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
French Guiana	3	3.8	7.5	11.3	100	0	0.75	2008	5.625
Gabon	1	0.1	0.3	0.5	100	0	0.75	2010	0.225
Gambia	1	0.1	0.3	0.5	100	0	0.75	1996	0.225
Ghana	4	49.0	70.0	91.0	100	0	0.75	2010	52.500
Guatemala	2	0.4	1.5	2.6	50	50	0.50	2005	0.750
Guinea	3	0.2	0.3	0.5	100	0	0.75	2002	0.225
Guinea-Bissau	1	0.1	0.3	0.5	100	0	0.75	2002	0.225
Guyana	3	7.5	15.0	22.5	100	0	0.75	2008	11.250
Honduras	1	0.1	0.3	0.5	50	50	0.50	1999	0.150
India	3	0.8	1.5	2.3	100	0	0.75	2010	1.125
Indonesia	4	122.5	175.0	227.5	17	83	0.33	2008	58.333
Ivory Coast	1	0.1	0.3	0.5	100	0	0.75	2012	0.225
Kenya	2	1.9	7.5	13.1	100	0	0.75	2002	5.625

Kyrgyzstan	2	1.9	7.5	13.1	50	50	0.50	2004	3.750
Lao Peoples Democratic Republic	3	0.7	1.3	2.0	100	0	0.75	2007	0.975
Lesotho	1	0.1	0.3	0.5	100	0	0.75	2002	0.225
Liberia	1	0.1	0.3	0.5	100	0	0.75	2003	0.225
Madagascar	2	0.4	1.5	2.6	100	0	0.75	2003	1.125
Malawi	1	0.1	0.3	0.5	100	0	0.75	2001	0.225
Malaysia	2	0.9	3.5	6.1	50	50	0.50	1992	1.750
Mali	4	14.0	20.0	26.0	100	0	0.75	2011	15.000
Mauritania	1	0.1	0.3	0.5	100	0	0.75	2004	0.225
Mexico	2	1.9	7.5	13.1	50	50	0.50	2003	3.750
Mongolia	4	8.1	11.5	15.0	50	50	0.50	2007	5.750
Mozambique	3	2.0	4.0	6.0	100	0	0.75	2009	3.000
Nicaragua	3	0.8	1.5	2.3	50	50	0.50	1999	0.750
Niger	1	0.1	0.3	0.5	100	0	0.75	2000	0.225
Nigeria	3	10.0	20.0	30.0	100	0	0.75	2011	15.000
Panama	2	0.4	1.5	2.6	50	50	0.50	1999	0.750
Papua New Guinea	2	1.8	7.0	12.3	50	50	0.50	2010	3.500
Paraguay	1	0.1	0.3	0.5	100	0	0.75	2012	0.225
Peru	4	49.0	70.0	91.0	25	75	0.38	2010	26.250
Philippines	4	49.0	70.0	91.0	25	75	0.38	2010	26.250
Russia	2	2.8	11.0	19.3	50	50	0.50	2001	5.500
Rwanda	1	0.1	0.3	0.5	100	0	0.75	1992	0.225
Senegal	2	0.4	1.5	2.6	100	0	0.75	2010	1.125
Sierra Leone	1	0.1	0.3	0.5	100	0	0.75	2004	0.225
South Africa	2	1.9	7.5	13.1	50	50	0.50	2005	3.750
Sudan	3	30.0	60.0	90.0	100	0	0.75	2011	45.000
Suriname	3	3.8	7.5	11.3	100	0	0.75	2008	5.625
Tajikistan	2	1.0	4.0	7.0	100	0	0.75	1996	3.000
Tanzania	4	31.5	45.0	58.5	100	0	0.75	2009	33.750
Thailand	2	0.4	1.5	2.6	100	0	0.75	2007	1.125
Togo	2	1.0	4.0	7.0	100	0	0.75	2002	3.000
Uganda	3	0.4	0.8	1.2	100	0	0.75	2008	0.600
Uzbekistan	1	0.1	0.3	0.5	100	0	0.75	2001	0.225
Venezuela	3	7.5	15.0	22.5	25	75	0.38	2005	5.625
Viet Nam	2	1.9	7.5	13.1	50	50	0.50	2001	3.750
Zambia	1	0.1	0.3	0.5	100	0	0.75	2008	0.225
Zimbabwe	3	12.5	25.0	37.5	20	80	0.35	2009	8.750

^a Class 1 = presence/absence, no quantitative information, error can be greater than $\pm 100\%$ (25 countries); class 2 = some indication of quantity of Hg used, estimated average error $\pm 75\%$ (20 countries); class 3 = quantitative data but not significantly updated within past five years, error $\pm 50\%$ (17 countries); class 4 = recent quantitative data; error $\pm 30\%$; ^b emission factor for concentrate amalgamation = 0.75 (1/1.3); Emission factor for whole ore amalgamation = 0.25 (1/4).

Annex 3: Method used to estimate 2010 mercury emissions to air from wastes associated with intentional use sectors, including an example calculation

Mercury emissions to air from certain intentional use sectors (see below) are produced using a slightly different but comparable methodology to that applied to calculate emissions from unintentional emission sectors (see Annex 1). Since national consumption data are unavailable in most cases, use is made of available data on regional patterns of consumption of Hg and Hg-containing products. Mercury releases at various points in the life-cycle of these products are calculated using assumptions regarding rates of breakage, waste handling, and factors for emissions to air, etc.

The new method applied is a variation of the method used in the 2005 inventory (AMAP/UNEP, 2008) where product-related Hg emissions from eleven regions of the world were estimated. The new methodology allows for a consistent and transparent treatment and calculation of product-related Hg emissions for each individual country, also taking country-specific information into account, where available. The method is schematically described in Figure A3.1.

The input data consist of estimated Hg consumption in one year (2010) covering the product groups: batteries, measuring devices, lamps, electrical and electronic devices, dental applications, and other uses (Table A3.1).

The consumption is estimated for each product group for eleven regions of the world; East and Southeast Asia, South Asia, European Union, CIS and other European countries, Middle Eastern States, North Africa, Sub-Saharan Africa, North America, Central America and the Caribbean, South

America, Australia New Zealand and Oceania. Consumption in this context refers to the region where the product is used and thus subsequently ends up in the waste stream, and not the region where it was produced. Very recent information on consumption (received too late to introduce into the calculations) indicates that some of the data presented in Table A3.1 for dental applications may need to be revised, and values for measuring devices in particular may be considerably higher, especially those for East and Southeast Asia.

In order to estimate the consumption in each country of the world, the consumption figures (for batteries, measuring devices, lamps, electrical devices and other uses – see Table A3.1) as compiled by Maxson (pers. comm., 2012) for each region were distributed between the countries in that region based on Gross Domestic Product (GDP) at Purchasing Power Parity (PPP). GDP-PPP data for individual countries were obtained from the data catalogue at the World Bank (World Bank, 2012) and where countries were not available in the list from the World Bank, from the World Factbook by the CIA (CIA, 2012). In the model, the estimated amount of Hg in products consumed in a country is distributed to four different initial pathways (Figure A3.1) using distribution factors. The main initial paths of the products containing Hg are collection for safe storage (no emissions assumed), breakage and releases of Hg during use, paths to the waste stream (with further differentiation of waste pathways), and finally products remaining 'in use' in society. It should be pointed out that as a result of this distribution, where some of the Hg contained in

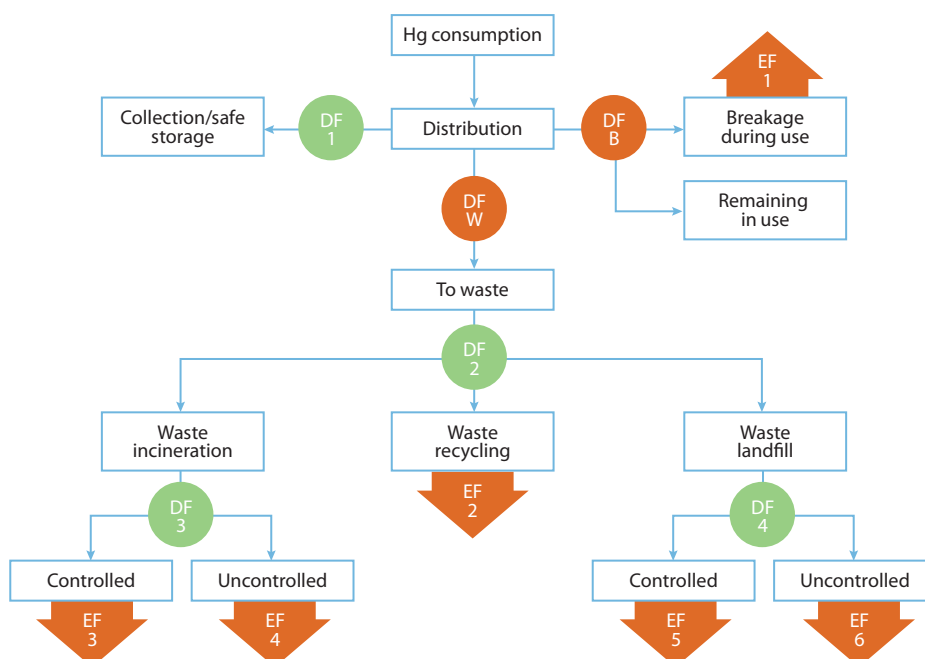


Figure A3.1. Schematic representation of the model used to estimate mercury emissions from waste streams associated with intentional use sectors.

Table A3.1. Mercury consumption in products by world region and application, 2010. Source: Maxson (2012, pers. comm.).

	Batteries	Measuring devices	Lamps	Electrical devices	Other use ^a	Dental applications ^b	Total
Average, t							
East and Southeast Asia	191	98	42	50	56	67	504
South Asia	26	27	13	18	21	24	129
European Union (27 countries)	23	15	18	2	105	90	253
CIS and other European countries	7	17	7	10	12	10	63
Middle Eastern States	5	13	6	7	6	16	53
North Africa	2	5	2	4	2	5	20
Sub-Saharan Africa	4	9	4	6	5	6	34
North America	11	34	15	43	76	34	213
Central America and the Caribbean	4	10	4	5	7	17	47
South America	16	18	10	10	13	33	100
Australia New Zealand and Oceania	2	4	2	3	2	4	17
Total	291	250	123	158	305	306	1433
Minimum, t							
East and Southeast Asia	153	89	38	45	43	62	430
South Asia	17	25	11	16	14	19	102
European Union (27 countries)	18	8	14	1	73	81	194
CIS and other European countries	6	15	6	9	9	10	56
Middle Eastern States	4	11	5	6	5	12	43
North Africa	2	4	2	3	2	4	17
Sub-Saharan Africa	3	8	3	5	4	5	28
North America	9	29	12	40	53	31	174
Central America and the Caribbean	3	9	4	4	6	14	40
South America	13	17	8	9	11	29	87
Australia New Zealand and Oceania	2	4	2	2	2	3	15
Total	230	219	105	140	222	270	1186
Maximum, t							
East and Southeast Asia	228	107	45	54	68	71	573
South Asia	34	30	14	19	27	28	152
European Union (27 countries)	28	22	21	3	137	99	309
CIS and other European countries	8	18	8	11	15	11	72
Middle Eastern States	6	14	6	8	7	19	60
North Africa	2	5	2	4	3	6	22
Sub-Saharan Africa	5	10	4	7	5	7	38
North America	13	39	18	45	100	38	253
Central America and the Caribbean	5	10	4	5	9	19	52
South America	19	20	11	11	15	38	114
Australia New Zealand and Oceania	2	5	2	3	3	5	20
Total	350	280	135	170	389	341	1664

^a The 'other use' category includes, for example, pesticides, fungicides, laboratory chemicals, polyurethane elastomers, pharmaceuticals, preservative in paints, traditional medicines, cultural and ritual uses, cosmetics – especially skin-lightening creams, etc. ^b Consumption in dental applications is not included in the calculations described in this Annex; the methodology employed to calculate emissions from dental amalgam use associated with human cremation are described in Annex 4.

products consumed in one year will remain in use in society, not all Hg contained in products is accounted for. This remaining Hg will of course in future years be distributed to one of the endpoints as the product reaches its end of life.

The share of Hg in products entering the waste stream is distributed among waste recycling, waste incineration and waste landfill. The amounts of Hg going to waste incineration and waste landfill are further distributed between two levels of waste management, controlled and uncontrolled waste incineration and controlled and uncontrolled waste landfill. Controlled in this context represents waste incineration with efficient air pollution abatement installed and controlled, well managed landfill with relatively low expected emissions of Hg. The uncontrolled incineration implies no or poor abatement of air emissions, and unmanaged landfills (or waste dumping) includes a higher occurrence of, for example, fires where higher Hg emissions would be expected.

In order to take into account varying waste management practices, four different ‘profiles’ of distribution factors and emissions factors were assumed. Each country has been assigned one of these four generic profiles based on assumptions (and available information) regarding national/regional waste handling practices, including discussions with regional representatives (see Section 2.2.3.1).

In the model, several assumptions regarding distribution factors and emission factors have been made. Discussions were held with representatives from all of the world’s regions and assumptions have been adjusted accordingly. More or less rough generalisations are however inevitable in order to perform harmonised and transparent calculations for all individual countries, since country-specific information in most cases is scarce or nonexistent.

The initial distribution factors determine the amount distributed to the waste stream. Table A3.2 presents the general distribution factors used for the four different profiles. The distribution for break and release during use, as well as the share remaining in use in society are the same for all profiles, while the share collected for safe storage varies.

The waste stream distribution pathways, given as distribution factors, are presented in Table A3.3. There are different assumptions regarding the share of Hg contained in products which is recycled, as well as on the shares going to waste incineration and landfill. For profiles 3 and 4 the distributions between recycling, incineration and landfill are the same. A differentiation is introduced in the specific distribution factors for the share of the incinerated and landfilled waste that is treated under controlled or uncontrolled conditions.

Table A3.2. Initial distribution factors for mercury-containing products.

Profile	Collection/safe storage	Breakage during use	Remain accumulated in society	To the waste stream	Total
1	15%	3.5%	30%	51.5%	100%
2	5%	3.5%	30%	61.5%	100%
3	1%	3.5%	30%	65.5%	100%
4	1%	3.5%	30%	65.5%	100%

Table A3.3. Waste distribution factors (upper part of the table) and specific distribution factors (lower part of the table) for controlled and uncontrolled waste incineration and waste landfill.

Profile	Waste distribution pathways				
	Recycling	Incineration		Landfill	
1	17%	18%		65%	
2	4%	12%		84%	
3	2%	5%		93%	
4	2%	5%		93%	
		controlled	uncontrolled	controlled	uncontrolled
1		100%	0%	60%	40%
2		40%	60%	30%	70%
3		20%	80%	30%	70%
4		15%	85%	10%	90%

Table A3.4. Emission factors (fraction emitted) applied to distributed amounts of mercury in products.

Profile	Break/release during use	Waste recycling	Waste incineration		Landfill	
			controlled	uncontrolled	controlled	uncontrolled
1	0.1	0.03	0.1	0.9	0.05	0.07
2	0.1	0.03	0.1	0.9	0.05	0.14
3	0.1	0.03	0.1	0.9	0.05	0.14
4	0.1	0.03	0.1	0.9	0.05	0.23

At this stage in the model calculations, the initial amount of Hg in products in a specific country has been distributed to all endpoints in the model (Figure A3.1) where emissions to air can occur. Emissions are calculated by applying emission factors (EF) according to Table A3.4 to the distributed individual amounts of Hg. For all endpoints, except for uncontrolled landfill, the EFs are the same for all assigned generic profiles of waste management. The expected releases of Hg from uncontrolled landfills are highly dependent on the frequency and duration of landfill fires. The more landfills under fire, the more Hg will be released. Rough assumptions and simplifications, largely based on Maxson (2009), have been applied for developing profile EFs for uncontrolled landfills, taking landfill fires into account.

It should be noted that where relevant national information was available, factors applied to specific countries were adjusted accordingly, such was the case for example for the distribution factors applied in the case of Japan and Republic of Korea.

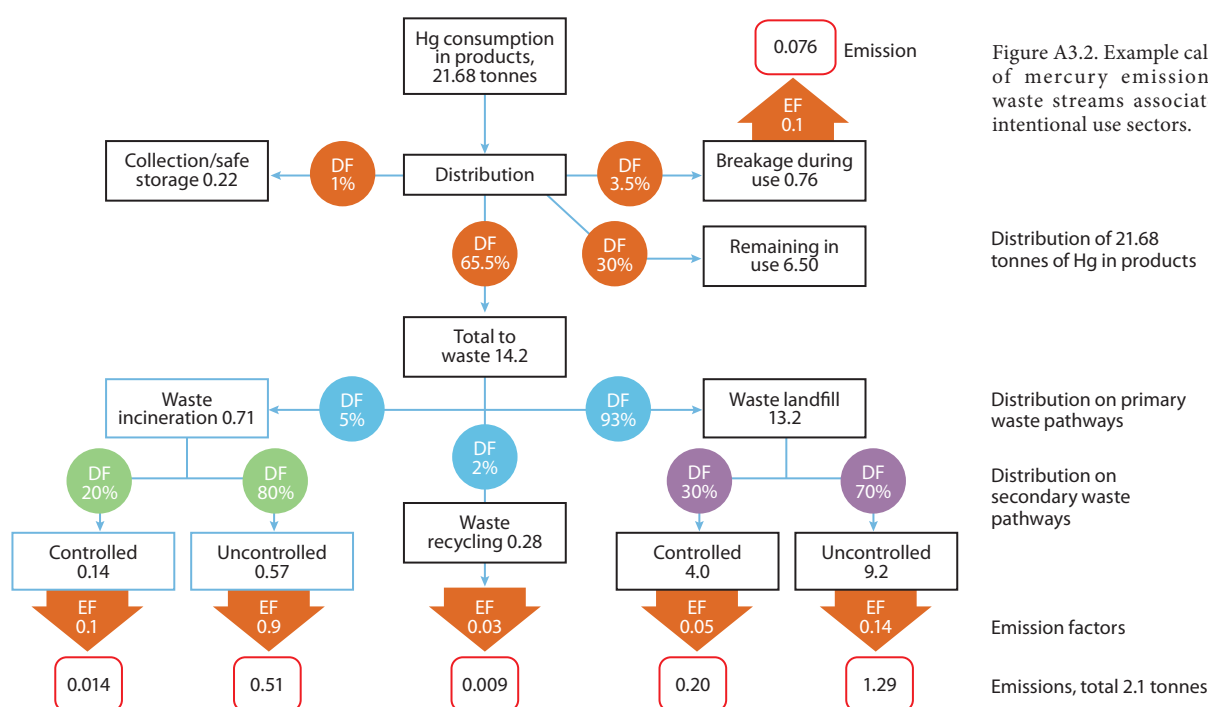
In the 2010 inventory, emissions using the above methodology are quantified under two main categories: emissions associated with controlled incineration (WI) and all other (waste) components (WASOTH). The WI component is assumed to be associated with incineration at (large incineration) facilities with applied APC technology. The amount of Hg calculated as emitted

from waste incineration in this work only includes the product groups concerned in this section. Additional emissions of Hg could arise from incineration of other types of Hg-containing waste, such as sewage sludge, industrial wastes, etc.

Example calculation

The following example shows the calculation scheme applied to estimate product waste emissions for Mexico. Mexico belongs to the Central America and the Caribbean region, which has an estimated consumption of Hg in intentional use products (batteries, measuring control devices/lamps, electronic devices and other – with dental uses excluded) of 30 tonnes (see Table A3.1). Based on GDP-PPP, 21.68 tonnes of this Hg consumption is attributed to Mexico.

Under the regionalisation approach described in Section 2.2.3.1, Mexico's general waste stream characterisation and waste management practices are best described by Profile 3 (see Tables A3.2 to A3.4). The flow chart Figure A3.2 illustrates how, on this basis, emission estimates to air totaling about 2.1 tonnes are calculated; of which about 0.014 tonnes are estimated to be emitted from controlled waste incineration.



Annex 4: Method used to estimate 2010 mercury emissions to air from use in dental amalgam and human cremation

Emissions from use of Hg in dental amalgam fillings can occur during the preparation of the amalgams and their subsequent removal and disposal in wastes. They can also occur when human remains with amalgam fillings are cremated. Emissions associated with the latter (i.e., cremation sources), were estimated using a similar approach to that employed for estimating emissions associated with other intentional-use sectors. That is to say, Hg consumption in dentistry (see Annex 3, Table A3.1) was combined with assumptions regarding its use and fate. Emissions were calculated based on an emission factor of 0.04 g per g Hg consumption – derived using the UNEP Toolkit default factor of 2.5 g per cremation and an average per capita (dental) consumption based on the European average, which may result in an overestimation of emissions for countries where the average number of amalgams per person will be lower than the European average.

Mercury amounts associated with fillings in cremated human remains were allocated to countries based on regional consumption statistics and population distributions, also taking into account factors such as religious practices and regulations in some countries concerning human cremation.

Owing to information regarding increasing use of air pollution control devices (including activated carbon systems) at crematoria in some countries, emissions from cremation sources in countries in the EU27 region and some countries in Asia (Japan, Republic of Korea, Taiwan) were reduced assuming an abatement of 75% of the emission.

Annex 5: Activity data used in the calculation of emission estimates

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
AFG	Afghanistan	CEM	CEM	50	kt	2009	USGS, 2012 (2009 data)
AGO	Angola	CEM	CEM	1800	kt	2009	USGS, 2012 (2009 data)
AGO	Angola	CSP	CSP-C	10	kt	2010	UNEP, 2012
AGO	Angola	OR	CO-OR	1851	kt	2009	IEA-SB
AGO	Angola	SC-DR-oil	CO-HF-DR	14	kt	2009	IEA-SB
AGO	Angola	SC-DR-oil	CO-LF-DR	1649	kt	2009	IEA-SB
AGO	Angola	SC-IND-gas	NG-IND	26220	TJ	2009	IEA-SB
AGO	Angola	SC-IND-oil	CO-HF-IND	102	kt	2009	IEA-SB
AGO	Angola	SC-IND-oil	CO-LF-IND	244	kt	2009	IEA-SB
AGO	Angola	SC-PP-oil	CO-HF-PP	165	kt	2009	IEA-SB
AGO	Angola	SC-PP-oil	CO-LF-PP	152	kt	2009	IEA-SB
ALB	Albania	CEM	CEM	740	kt	2009	USGS, 2012 (2009 data)
ALB	Albania	OR	CO-OR	319	kt	2009	IEA-SB
ALB	Albania	SC-DR-gas	NG-DR	28	TJ	2009	IEA-SB
ALB	Albania	SC-DR-oil	CO-HF-DR	5	kt	2009	IEA-SB
ALB	Albania	SC-DR-oil	CO-LF-DR	422	kt	2009	IEA-SB
ALB	Albania	SC-IND-coal	BC-IND	262	kt	2009	IEA-SB
ALB	Albania	SC-IND-gas	NG-IND	18	TJ	2009	IEA-SB
ALB	Albania	SC-IND-oil	CO-HF-IND	8	kt	2009	IEA-SB
ALB	Albania	SC-IND-oil	CO-LF-IND	17	kt	2009	IEA-SB
ALB	Albania	SC-PP-coal	BC-L-PP	1	kt	2009	IEA-SB
ALB	Albania	SC-PP-gas	NG-PP	254	TJ	2009	IEA-SB
ALB	Albania	SC-PP-oil	CO-HF-PP	9	kt	2009	IEA-SB
ALB	Albania	SC-PP-oil	CO-LF-PP	10	kt	2009	IEA-SB
ANT	Netherlands Antilles	OR	CO-OR	9505	kt	2009	IEA-SB
ANT	Netherlands Antilles	SC-DR-oil	CO-LF-DR	303	kt	2009	IEA-SB
ANT	Netherlands Antilles	SC-IND-oil	CO-HF-IND	142	kt	2009	IEA-SB
ANT	Netherlands Antilles	SC-PP-oil	CO-HF-PP	533	kt	2009	IEA-SB
ANT	Netherlands Antilles	SC-PP-oil	CO-LF-PP	18	kt	2009	IEA-SB
ARE	United Arab Emirates	CEM	CEM	16000	kt	2009	USGS, 2012 (2009 data)
ARE	United Arab Emirates	CSP	CSP-C	9	kt	2010	UNEP, 2012
ARE	United Arab Emirates	NFMP	AL-P	1400	kt	2010	USGS, 2012 (2010 data)
ARE	United Arab Emirates	NFMP	PB-S	2000	t	2009	USGS, 2012 (2010 data)
ARE	United Arab Emirates	OR	CO-OR	7884	kt	2009	IEA-SB
ARE	United Arab Emirates	OR	NGL-OR	10451	kt	2009	IEA-SB
ARE	United Arab Emirates	SC-DR-oil	CO-LF-DR	4205	kt	2009	IEA-SB
ARE	United Arab Emirates	SC-IND-gas	NG-IND	1154413	TJ	2009	IEA-SB
ARE	United Arab Emirates	SC-IND-oil	CO-HF-IND	1168	kt	2009	IEA-SB
ARE	United Arab Emirates	SC-PP-gas	NG-PP	1131677	TJ	2009	IEA-SB
ARE	United Arab Emirates	SC-PP-oil	CO-HF-PP	43	kt	2009	IEA-SB
ARE	United Arab Emirates	SC-PP-oil	CO-LF-PP	497	kt	2009	IEA-SB
ARG	Argentina	CEM	CEM	10000	kt	2009	USGS, 2012 (2009 data)
ARG	Argentina	CSP	CSP-P	77700	t	2010	National information: Devia, 2012. (pers. comm.)
ARG	Argentina	GP	GP-L	47000	kg	2009	USGS, 2012 (2009 data)
ARG	Argentina	NFMP	AL-P	415	kt	2010	USGS, 2012 (2010 data)
ARG	Argentina	NFMP	PB-P	12558	t	2009	USGS, 2012 (2010 data)
ARG	Argentina	NFMP	PB-S	70000	t	2009	USGS, 2012 (2010 data)
ARG	Argentina	NFMP	ZN-P	32989	t	2009	USGS, 2012 (2010 data)
ARG	Argentina	NFMP	ZN-S	2639	t	2009	USGS, 2012 (2010 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
ARG	Argentina	OR	CO-OR	25765854	t	2010	National information: Devia, 2012. (pers. comm.)
ARG	Argentina	PIP-C	COC-IND	974	kt	2009	IEA-SB
ARG	Argentina	PISP	PIP	2532	kt	2010	Worldsteel Association, 2011
ARG	Argentina	SC-DR-gas	NG-DR	500692	TJ	2009	IEA-SB
ARG	Argentina	SC-DR-oil	CO-HF-DR	53	kt	2009	IEA-SB
ARG	Argentina	SC-DR-oil	CO-LF-DR	8819	kt	2009	IEA-SB
ARG	Argentina	SC-IND-gas	NG-IND	290097	TJ	2009	IEA-SB
ARG	Argentina	SC-IND-oil	CO-HF-IND	63	kt	2009	IEA-SB
ARG	Argentina	SC-IND-oil	CO-LF-IND	59	kt	2009	IEA-SB
ARG	Argentina	SC-PP-coal	HC-B-PP	657539	t	2010	National information: Devia, 2012. (pers. comm.)
ARG	Argentina	SC-PP-gas	NG-PP	870747	TJ	2009	IEA-SB
ARG	Argentina	SC-PP-oil	CO-HF-PP	2732	kt	2009	IEA-SB
ARG	Argentina	SC-PP-oil	CO-LF-PP	823	kt	2009	IEA-SB
ARG	Argentina	SC-PP-oil	CO-PP	1	kt	2009	IEA-SB
ARM	Armenia	CEM	CEM	750	kt	2009	USGS, 2012 (2009 data)
ARM	Armenia	GP	GP-L	944	kg	2009	USGS, 2012 (2009 data)
ARM	Armenia	NFMP	CU-P	6858	t	2009	USGS, 2012 (2009 data)
ARM	Armenia	SC-DR-gas	NG-DR	33721	TJ	2009	IEA-SB
ARM	Armenia	SC-DR-oil	CO-HF-DR	1	kt	2009	IEA-SB
ARM	Armenia	SC-DR-oil	CO-LF-DR	118	kt	2009	IEA-SB
ARM	Armenia	SC-IND-gas	NG-IND	19048	TJ	2009	IEA-SB
ARM	Armenia	SC-PP-gas	NG-PP	12781	TJ	2009	IEA-SB
AUS	Australia (and Christmas Is.)	CEM	CEM	8500	kt	2009	USGS, 2012 (2009 data)
AUS	Australia (and Christmas Is.)	GP	GP-L	222000	kg	2009	USGS, 2012 (2009 data)
AUS	Australia (and Christmas Is.)	NFMP	AL-P	1928	kt	2010	USGS, 2012 (2010 data)
AUS	Australia (and Christmas Is.)	NFMP	CU-P	422000	t	2009	USGS, 2012 (2009 data)
AUS	Australia (and Christmas Is.)	NFMP	PB-P	204000	t	2009	USGS, 2012 (2010 data)
AUS	Australia (and Christmas Is.)	NFMP	PB-S	25000	t	2009	USGS, 2012 (2010 data)
AUS	Australia (and Christmas Is.)	NFMP	ZN-P	525000	t	2009	USGS, 2012 (2010 data)
AUS	Australia (and Christmas Is.)	NFMP	ZN-S	6000	t	2009	USGS, 2012 (2010 data)
AUS	Australia (and Christmas Is.)	OR	CO-OR	26983	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	PIP-C	COC-IND	976	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	PISP	PIP	6005	kt	2010	Worldsteel Association, 2011
AUS	Australia (and Christmas Is.)	SC-DR-coal	BC-DR	179	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-DR-coal	HC-DR	24	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-DR-gas	NG-DR	206412	TJ	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-DR-oil	CO-HF-DR	148	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-DR-oil	CO-LF-DR	11854	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-coal	BC-IND	2959	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-coal	HC-IND	1851	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-gas	NG-IND	377491	TJ	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-oil	CO-HF-IND	885	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-oil	CO-IND	37	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-IND-oil	CO-LF-IND	2533	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-coal	BC-L-PP	65846	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-coal	BC-S-PP	30766	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-coal	HC-B-PP	27393	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-gas	NG-PP	598878	TJ	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-oil	CO-HF-PP	190	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-oil	CO-LF-PP	1339	kt	2009	IEA-SB
AUS	Australia (and Christmas Is.)	SC-PP-oil	CO-PP	106	kt	2009	IEA-SB
AUT	Austria	CEM	CEM	4600	kt	2009	USGS, 2012 (2009 data)

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AUT	Austria	NFMP	CU-S	90800	t	2009	USGS, 2012 (2009 data)
AUT	Austria	NFMP	PB-S	23000	t	2009	USGS, 2012 (2010 data)
AUT	Austria	OR	CO-OR	8306	kt	2009	IEA-SB
AUT	Austria	OR	NGL-OR	93	kt	2009	IEA-SB
AUT	Austria	PIP-C	COC-IND	228	kt	2009	IEA-SB
AUT	Austria	PISP	PIP	5621	kt	2010	Worldsteel Association, 2011
AUT	Austria	SC-DR-coal	BC-DR	3	kt	2009	IEA-SB
AUT	Austria	SC-DR-coal	HC-DR	20	kt	2009	IEA-SB
AUT	Austria	SC-DR-gas	NG-DR	82094	TJ	2009	IEA-SB
AUT	Austria	SC-DR-oil	CO-HF-DR	80	kt	2009	IEA-SB
AUT	Austria	SC-DR-oil	CO-LF-DR	6627	kt	2009	IEA-SB
AUT	Austria	SC-IND-coal	BC-IND	76	kt	2009	IEA-SB
AUT	Austria	SC-IND-coal	HC-IND	362	kt	2009	IEA-SB
AUT	Austria	SC-IND-gas	NG-IND	105714	TJ	2009	IEA-SB
AUT	Austria	SC-IND-oil	CO-HF-IND	256	kt	2009	IEA-SB
AUT	Austria	SC-IND-oil	CO-LF-IND	400	kt	2009	IEA-SB
AUT	Austria	SC-PP-coal	HC-B-PP	1206	kt	2009	IEA-SB
AUT	Austria	SC-PP-gas	NG-PP	134125	TJ	2009	IEA-SB
AUT	Austria	SC-PP-oil	CO-HF-PP	297	kt	2009	IEA-SB
AUT	Austria	SC-PP-oil	CO-LF-PP	10	kt	2009	IEA-SB
AZE	Azerbaijan	CEM	CEM	1283	kt	2009	USGS, 2012 (2009 data)
AZE	Azerbaijan	CSP	CSP-C	145	kt	2010	UNEP, 2012
AZE	Azerbaijan	GP	GP-L	353	kg	2009	USGS, 2012 (2009 data)
AZE	Azerbaijan	NFMP	AL-P	30	kt	2010	USGS, 2012 (2010 data)
AZE	Azerbaijan	OR	CO-OR	4042	kt	2009	IEA-SB
AZE	Azerbaijan	OR	NGL-OR	2062	kt	2009	IEA-SB
AZE	Azerbaijan	SC-DR-gas	NG-DR	110635	TJ	2009	IEA-SB
AZE	Azerbaijan	SC-DR-oil	CO-HF-DR	6	kt	2009	IEA-SB
AZE	Azerbaijan	SC-DR-oil	CO-LF-DR	715	kt	2009	IEA-SB
AZE	Azerbaijan	SC-IND-gas	NG-IND	12721	TJ	2009	IEA-SB
AZE	Azerbaijan	SC-IND-oil	CO-HF-IND	78	kt	2009	IEA-SB
AZE	Azerbaijan	SC-IND-oil	CO-LF-IND	26	kt	2009	IEA-SB
AZE	Azerbaijan	SC-PP-gas	NG-PP	209113	TJ	2009	IEA-SB
AZE	Azerbaijan	SC-PP-oil	CO-HF-PP	164	kt	2009	IEA-SB
AZE	Azerbaijan	SC-PP-oil	CO-LF-PP	13	kt	2009	IEA-SB
BDI	Burundi	GP	GP-L	750	kg	2009	USGS, 2012 (2009 data)
BEL	Belgium	CEM	CEM	8200	kt	2009	USGS, 2012 (2009 data)
BEL	Belgium	CSP	CSP-C	495000	t	2010	OSPAR, 2011
BEL	Belgium	NFMP	CU-S	114400	t	2009	USGS, 2012 (2009 data)
BEL	Belgium	NFMP	PB-P	0	t	2009	USGS, 2012 (2010 data)
BEL	Belgium	NFMP	PB-S	109000	t	2009	USGS, 2012 (2010 data)
BEL	Belgium	NFMP	ZN-P	26000	t	2009	USGS, 2012 (2010 data)
BEL	Belgium	OR	CO-OR	31324	kt	2009	IEA-SB
BEL	Belgium	PIP-C	COC-IND	68	kt	2009	IEA-SB
BEL	Belgium	PISP	PIP	4688	kt	2010	Worldsteel Association, 2011
BEL	Belgium	SC-DR-coal	HC-DR	370	kt	2009	IEA-SB
BEL	Belgium	SC-DR-gas	NG-DR	245183	TJ	2009	IEA-SB
BEL	Belgium	SC-DR-oil	CO-HF-DR	106	kt	2009	IEA-SB
BEL	Belgium	SC-DR-oil	CO-LF-DR	10852	kt	2009	IEA-SB
BEL	Belgium	SC-IND-coal	BC-IND	152	kt	2009	IEA-SB
BEL	Belgium	SC-IND-coal	HC-IND	301	kt	2009	IEA-SB
BEL	Belgium	SC-IND-gas	NG-IND	185885	TJ	2009	IEA-SB
BEL	Belgium	SC-IND-oil	CO-HF-IND	445	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
BEL	Belgium	SC-IND-oil	CO-LF-IND	126	kt	2009	IEA-SB
BEL	Belgium	SC-PP-coal	HC-B-PP	1741	kt	2009	IEA-SB
BEL	Belgium	SC-PP-gas	NG-PP	232313	TJ	2009	IEA-SB
BEL	Belgium	SC-PP-oil	CO-HF-PP	368	kt	2009	IEA-SB
BEL	Belgium	SC-PP-oil	CO-LF-PP	9	kt	2009	IEA-SB
BEN	Benin	CEM	CEM	1500	kt	2009	USGS, 2012 (2009 data)
BEN	Benin	GP	GP-L	20	kg	2009	USGS, 2012 (2009 data)
BEN	Benin	SC-DR-oil	CO-LF-DR	355	kt	2009	IEA-SB
BEN	Benin	SC-IND-oil	CO-HF-IND	44	kt	2009	IEA-SB
BEN	Benin	SC-IND-oil	CO-LF-IND	4	kt	2009	IEA-SB
BEN	Benin	SC-PP-oil	CO-LF-PP	29	kt	2009	IEA-SB
BFA	Burkina Faso	CEM	CEM	30	kt	2009	USGS, 2012 (2009 data)
BFA	Burkina Faso	GP	GP-L	13500	kg	2009	USGS, 2012 (2009 data)
BGD	Bangladesh	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
BGD	Bangladesh	OR	CO-OR	1000	kt	2009	IEA-SB
BGD	Bangladesh	OR	NGL-OR	69	kt	2009	IEA-SB
BGD	Bangladesh	SC-DR-gas	NG-DR	123135	TJ	2009	IEA-SB
BGD	Bangladesh	SC-DR-oil	CO-LF-DR	2470	kt	2009	IEA-SB
BGD	Bangladesh	SC-IND-coal	HC-IND	800	kt	2009	IEA-SB
BGD	Bangladesh	SC-IND-gas	NG-IND	113745	TJ	2009	IEA-SB
BGD	Bangladesh	SC-IND-oil	CO-HF-IND	162	kt	2009	IEA-SB
BGD	Bangladesh	SC-IND-oil	CO-LF-IND	76	kt	2009	IEA-SB
BGD	Bangladesh	SC-PP-coal	HC-B-PP	457	kt	2009	IEA-SB
BGD	Bangladesh	SC-PP-gas	NG-PP	382786	TJ	2009	IEA-SB
BGD	Bangladesh	SC-PP-oil	CO-HF-PP	316	kt	2009	IEA-SB
BGD	Bangladesh	SC-PP-oil	CO-LF-PP	366	kt	2009	IEA-SB
BGR	Bulgaria	CEM	CEM	2662	kt	2009	USGS, 2012 (2009 data)
BGR	Bulgaria	GP	GP-L	4200	kg	2009	USGS, 2012 (2009 data)
BGR	Bulgaria	NFMP	CU-P	256200	t	2009	USGS, 2012 (2009 data)
BGR	Bulgaria	NFMP	CU-S	20000	t	2009	USGS, 2012 (2009 data)
BGR	Bulgaria	NFMP	PB-P	70000	t	2009	USGS, 2012 (2010 data)
BGR	Bulgaria	NFMP	PB-S	13000	t	2009	USGS, 2012 (2010 data)
BGR	Bulgaria	NFMP	ZN-T	92676	t	2009	USGS, 2012 (2010 data)
BGR	Bulgaria	OR	CO-OR	6247	kt	2009	IEA-SB
BGR	Bulgaria	PIP-C	COC-IND	65	kt	2009	IEA-SB
BGR	Bulgaria	PISP	PIP	441	kt	2008	Worldsteel Association, 2011
BGR	Bulgaria	SC-DR-coal	BC-DR	127	kt	2009	IEA-SB
BGR	Bulgaria	SC-DR-coal	HC-DR	193	kt	2009	IEA-SB
BGR	Bulgaria	SC-DR-gas	NG-DR	15423	TJ	2009	IEA-SB
BGR	Bulgaria	SC-DR-oil	CO-HF-DR	12	kt	2009	IEA-SB
BGR	Bulgaria	SC-DR-oil	CO-LF-DR	1631	kt	2009	IEA-SB
BGR	Bulgaria	SC-IND-coal	BC-IND	13	kt	2009	IEA-SB
BGR	Bulgaria	SC-IND-coal	HC-IND	239	kt	2009	IEA-SB
BGR	Bulgaria	SC-IND-gas	NG-IND	28020	TJ	2009	IEA-SB
BGR	Bulgaria	SC-IND-oil	CO-HF-IND	105	kt	2009	IEA-SB
BGR	Bulgaria	SC-IND-oil	CO-LF-IND	59	kt	2009	IEA-SB
BGR	Bulgaria	SC-PP-coal	BC-L-PP	24415	kt	2009	IEA-SB
BGR	Bulgaria	SC-PP-coal	HC-A-PP	1129	kt	2009	IEA-SB
BGR	Bulgaria	SC-PP-coal	HC-B-PP	1358	kt	2009	IEA-SB
BGR	Bulgaria	SC-PP-gas	NG-PP	44192	TJ	2009	IEA-SB
BGR	Bulgaria	SC-PP-oil	CO-HF-PP	177	kt	2009	IEA-SB
BGR	Bulgaria	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
BHR	Bahrain	CEM	CEM	800	kt	2009	USGS, 2012 (2009 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
BHR	Bahrain	NFMP	AL-P	870	kt	2010	USGS, 2012 (2010 data)
BHR	Bahrain	OR	CO-OR	12872	kt	2009	IEA-SB
BHR	Bahrain	SC-DR-oil	CO-LF-DR	432	kt	2009	IEA-SB
BHR	Bahrain	SC-IND-gas	NG-IND	137031	TJ	2009	IEA-SB
BHR	Bahrain	SC-PP-gas	NG-PP	230245	TJ	2009	IEA-SB
BIH	Bosnia-Herzegovina	CEM	CEM	1074	kt	2009	USGS, 2012 (2009 data)
BIH	Bosnia-Herzegovina	NFMP	AL-P	118	kt	2010	USGS, 2012 (2010 data)
BIH	Bosnia-Herzegovina	OR	CO-OR	978	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	PIP-C	COC-IND	22	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	PISP	PIP	243	kt	2008	Bilans, 2010
BIH	Bosnia-Herzegovina	SC-DR-coal	BC-DR	388	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-DR-gas	NG-DR	2895	TJ	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-DR-oil	CO-HF-DR	193	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-DR-oil	CO-LF-DR	559	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-IND-coal	BC-IND	164	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-IND-gas	NG-IND	3035	TJ	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-PP-coal	BC-L-PP	4962	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-PP-coal	BC-S-PP	5142	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-PP-gas	NG-PP	2650	TJ	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-PP-oil	CO-HF-PP	43	kt	2009	IEA-SB
BIH	Bosnia-Herzegovina	SC-PP-oil	CO-LF-PP	25	kt	2009	IEA-SB
BLR	Belarus	CEM	CEM	4350	kt	2009	USGS, 2012 (2009 data)
BLR	Belarus	OR	CO-OR	21634	kt	2009	IEA-SB
BLR	Belarus	PIP-C	COC-IND	56	kt	2009	IEA-SB
BLR	Belarus	SC-DR-coal	HC-DR	22	kt	2009	IEA-SB
BLR	Belarus	SC-DR-gas	NG-DR	83154	TJ	2009	IEA-SB
BLR	Belarus	SC-DR-oil	CO-HF-DR	47	kt	2009	IEA-SB
BLR	Belarus	SC-DR-oil	CO-LF-DR	2044	kt	2009	IEA-SB
BLR	Belarus	SC-IND-coal	HC-IND	12	kt	2009	IEA-SB
BLR	Belarus	SC-IND-gas	NG-IND	76008	TJ	2009	IEA-SB
BLR	Belarus	SC-IND-oil	CO-HF-IND	53	kt	2009	IEA-SB
BLR	Belarus	SC-IND-oil	CO-LF-IND	62	kt	2009	IEA-SB
BLR	Belarus	SC-PP-coal	HC-B-PP	30	kt	2009	IEA-SB
BLR	Belarus	SC-PP-gas	NG-PP	463966	TJ	2009	IEA-SB
BLR	Belarus	SC-PP-oil	CO-HF-PP	2623	kt	2009	IEA-SB
BLR	Belarus	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
BLZ	Belize	GP	GP-L	5	kg	2009	USGS, 2012 (2009 data)
BOL	Bolivia	CEM	CEM	2292	kt	2009	USGS, 2012 (2009 data)
BOL	Bolivia	GP	GP-L	7000	kg	2009	USGS, 2012 (2009 data)
BOL	Bolivia	NFMP	PB-T	269	t	2009	USGS, 2012 (2010 data)
BOL	Bolivia	OR	CO-OR	2018	kt	2009	IEA-SB
BOL	Bolivia	SC-DR-gas	NG-DR	16656	TJ	2009	IEA-SB
BOL	Bolivia	SC-DR-oil	CO-LF-DR	955	kt	2009	IEA-SB
BOL	Bolivia	SC-IND-gas	NG-IND	26155	TJ	2009	IEA-SB
BOL	Bolivia	SC-IND-oil	CO-HF-IND	2	kt	2009	IEA-SB
BOL	Bolivia	SC-IND-oil	CO-LF-IND	50	kt	2009	IEA-SB
BOL	Bolivia	SC-PP-gas	NG-PP	64425	TJ	2009	IEA-SB
BOL	Bolivia	SC-PP-oil	CO-LF-PP	31	kt	2009	IEA-SB
BRA	Brazil	CEM	CEM	63000	kt	2009	National information: Maioli, 2012. (pers. comm.)
BRA	Brazil	CSP	CSP-P	223.4	kt	2010	National information: Maioli, 2012. (pers. comm.)
BRA	Brazil	GP	GP-L	34800	kg	2010	National information: Maioli, 2012. (pers. comm.)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
BRA	Brazil	NFMP	AL-P	1536	kt	2010	USGS, 2012 (2010 data)
BRA	Brazil	NFMP	CU-P	176000	t	2009	USGS, 2012 (2009 data)
BRA	Brazil	NFMP	CU-S	31000	t	2009	USGS, 2012 (2009 data)
BRA	Brazil	NFMP	ZN-P	250000	t	2009	USGS, 2012 (2010 data)
BRA	Brazil	OR	CO-OR	90451	kt	2009	IEA-SB
BRA	Brazil	OR	NGL-OR	1346	kt	2009	IEA-SB
BRA	Brazil	PIP-C	COC-IND	950	kt	2009	IEA-SB
BRA	Brazil	PISP	PIP	34925	kt	2008	Worldsteel Association, 2011
BRA	Brazil	SC-DR-gas	NG-DR	100063	TJ	2009	IEA-SB
BRA	Brazil	SC-DR-oil	CO-HF-DR	1317	kt	2009	IEA-SB
BRA	Brazil	SC-DR-oil	CO-LF-DR	34348	kt	2009	IEA-SB
BRA	Brazil	SC-IND-coal	BC-IND	780	kt	2009	IEA-SB
BRA	Brazil	SC-IND-coal	HC-IND	3376	kt	2009	IEA-SB
BRA	Brazil	SC-IND-gas	NG-IND	315341	TJ	2009	IEA-SB
BRA	Brazil	SC-IND-oil	CO-HF-IND	3818	kt	2009	IEA-SB
BRA	Brazil	SC-IND-oil	CO-LF-IND	700	kt	2009	IEA-SB
BRA	Brazil	SC-PP-coal	BC-L-PP	1437	kt	2009	IEA-SB
BRA	Brazil	SC-PP-coal	BC-S-PP	2437	kt	2009	IEA-SB
BRA	Brazil	SC-PP-coal	HC-B-PP	78	kt	2009	IEA-SB
BRA	Brazil	SC-PP-gas	NG-PP	341548	TJ	2009	IEA-SB
BRA	Brazil	SC-PP-oil	CO-HF-PP	2227	kt	2009	IEA-SB
BRA	Brazil	SC-PP-oil	CO-LF-PP	1850	kt	2009	IEA-SB
BRB	Barbados	CEM	CEM	300	kt	2009	USGS, 2012 (2009 data)
BRN	Brunei Darussalam	CEM	CEM	220	kt	2009	USGS, 2012 (2009 data)
BRN	Brunei Darussalam	OR	CO-OR	483	kt	2009	IEA-SB
BRN	Brunei Darussalam	OR	NGL-OR	193	kt	2009	IEA-SB
BRN	Brunei Darussalam	SC-DR-gas	NG-DR	1205	TJ	2009	IEA-SB
BRN	Brunei Darussalam	SC-DR-oil	CO-LF-DR	130	kt	2009	IEA-SB
BRN	Brunei Darussalam	SC-IND-gas	NG-IND	35461	TJ	2009	IEA-SB
BRN	Brunei Darussalam	SC-IND-oil	CO-LF-IND	88	kt	2009	IEA-SB
BRN	Brunei Darussalam	SC-PP-gas	NG-PP	84811	TJ	2009	IEA-SB
BRN	Brunei Darussalam	SC-PP-oil	CO-HF-PP	84	kt	2009	IEA-SB
BRN	Brunei Darussalam	SC-PP-oil	CO-LF-PP	9	kt	2009	IEA-SB
BTN	Bhutan	CEM	CEM	180	kt	2009	USGS, 2012 (2009 data)
BWA	Botswana	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
BWA	Botswana	NFMP	CU-P	24382	t	2009	USGS, 2012 (2009 data)
BWA	Botswana	SC-DR-coal	HC-DR	15	kt	2009	IEA-SB
BWA	Botswana	SC-DR-oil	CO-LF-DR	281	kt	2009	IEA-SB
BWA	Botswana	SC-IND-coal	HC-IND	298	kt	2009	IEA-SB
BWA	Botswana	SC-IND-oil	CO-HF-IND	9	kt	2009	IEA-SB
BWA	Botswana	SC-IND-oil	CO-LF-IND	119	kt	2009	IEA-SB
BWA	Botswana	SC-PP-coal	HC-B-PP	383	kt	2009	IEA-SB
CAF	Central African Republic	GP	GP-L	10	kg	2009	USGS, 2012 (2009 data)
CAN	Canada	CEM	CEM	10985	kt	2009	USGS, 2012 (2009 data)
CAN	Canada	GP	GP-L	97367	kg	2009	USGS, 2012 (2009 data)
CAN	Canada	NFMP	AL-P	2963	kt	2010	USGS, 2012 (2010 data)
CAN	Canada	NFMP	CU-P	316510	t	2009	USGS, 2012 (2009 data)
CAN	Canada	NFMP	CU-S	29733	t	2009	USGS, 2012 (2009 data)
CAN	Canada	NFMP	PB-P	101484	t	2009	USGS, 2012 (2010 data)
CAN	Canada	NFMP	PB-S	157370	t	2009	USGS, 2012 (2010 data)
CAN	Canada	NFMP	ZN-P	685504	t	2009	USGS, 2012 (2010 data)
CAN	Canada	OR	CO-OR	68045	kt	2009	IEA-SB
CAN	Canada	OR	NGL-OR	1943	kt	2009	IEA-SB

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CAN	Canada	PIP-C	COC-IND	705	kt	2009	IEA-SB
CAN	Canada	PISP	PIP	7666	kt	2010	Worldsteel Association, 2011
CAN	Canada	SC-DR-coal	BC-DR	81	kt	2009	IEA-SB
CAN	Canada	SC-DR-gas	NG-DR	1319644	TJ	2009	IEA-SB
CAN	Canada	SC-DR-oil	CO-HF-DR	2148	kt	2009	IEA-SB
CAN	Canada	SC-DR-oil	CO-LF-DR	22831	kt	2009	IEA-SB
CAN	Canada	SC-IND-coal	HC-IND	1821	kt	2009	IEA-SB
CAN	Canada	SC-IND-gas	NG-IND	1116059	TJ	2009	IEA-SB
CAN	Canada	SC-IND-oil	CO-HF-IND	1026	kt	2009	IEA-SB
CAN	Canada	SC-IND-oil	CO-LF-IND	2339	kt	2009	IEA-SB
CAN	Canada	SC-PP-coal	BC-L-PP	10084	kt	2009	IEA-SB
CAN	Canada	SC-PP-coal	BC-S-PP	28745	kt	2009	IEA-SB
CAN	Canada	SC-PP-coal	HC-B-PP	3670	kt	2009	IEA-SB
CAN	Canada	SC-PP-gas	NG-PP	1063251	TJ	2009	IEA-SB
CAN	Canada	SC-PP-oil	CO-HF-PP	1704	kt	2009	IEA-SB
CAN	Canada	SC-PP-oil	CO-LF-PP	99	kt	2009	IEA-SB
CHE	Switzerland	CEM	CEM	4000	kt	2009	USGS, 2012 (2009 data)
CHE	Switzerland	CSP	CSP-C	27000	t	2010	OSPAR, 2011
CHE	Switzerland	NFMP	PB-S	8000	t	2009	USGS, 2012 (2010 data)
CHE	Switzerland	OR	CO-OR	4748	kt	2009	IEA-SB
CHE	Switzerland	PIP-C	COC-IND	22	kt	2009	IEA-SB
CHE	Switzerland	PISP	PIP	100	kt	2008	Bilans, 2010
CHE	Switzerland	SC-DR-coal	HC-DR	14	kt	2009	IEA-SB
CHE	Switzerland	SC-DR-gas	NG-DR	77067	TJ	2009	IEA-SB
CHE	Switzerland	SC-DR-oil	CO-LF-DR	5844	kt	2009	IEA-SB
CHE	Switzerland	SC-IND-coal	BC-IND	66	kt	2009	IEA-SB
CHE	Switzerland	SC-IND-coal	HC-IND	141	kt	2009	IEA-SB
CHE	Switzerland	SC-IND-gas	NG-IND	38020	TJ	2009	IEA-SB
CHE	Switzerland	SC-IND-oil	CO-HF-IND	66	kt	2009	IEA-SB
CHE	Switzerland	SC-IND-oil	CO-LF-IND	629	kt	2009	IEA-SB
CHE	Switzerland	SC-PP-gas	NG-PP	9664	TJ	2009	IEA-SB
CHE	Switzerland	SC-PP-oil	CO-HF-PP	21	kt	2009	IEA-SB
CHE	Switzerland	SC-PP-oil	CO-LF-PP	19	kt	2009	IEA-SB
CHL	Chile	CEM	CEM	3876	kt	2009	USGS, 2012 (2009 data)
CHL	Chile	GP	GP-L	40834	kg	2009	USGS, 2012 (2009 data)
CHL	Chile	NFMP	CU-P	1522300	t	2009	USGS, 2012 (2009 data)
CHL	Chile	OR	CO-OR	10049	kt	2009	IEA-SB
CHL	Chile	PIP-C	COC-IND	83	kt	2009	IEA-SB
CHL	Chile	PISP	PIP	635	kt	2010	Worldsteel Association, 2011
CHL	Chile	SC-DR-coal	HC-DR	15	kt	2009	IEA-SB
CHL	Chile	SC-DR-gas	NG-DR	24471	TJ	2009	IEA-SB
CHL	Chile	SC-DR-oil	CO-HF-DR	332	kt	2009	IEA-SB
CHL	Chile	SC-DR-oil	CO-LF-DR	3730	kt	2009	IEA-SB
CHL	Chile	SC-IND-coal	HC-IND	186	kt	2009	IEA-SB
CHL	Chile	SC-IND-gas	NG-IND	7089	TJ	2009	IEA-SB
CHL	Chile	SC-IND-oil	CO-HF-IND	637	kt	2009	IEA-SB
CHL	Chile	SC-IND-oil	CO-LF-IND	1961	kt	2009	IEA-SB
CHL	Chile	SC-PP-coal	HC-B-PP	5849	kt	2009	IEA-SB
CHL	Chile	SC-PP-gas	NG-PP	35282	TJ	2009	IEA-SB
CHL	Chile	SC-PP-oil	CO-HF-PP	272	kt	2009	IEA-SB
CHL	Chile	SC-PP-oil	CO-LF-PP	1876	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	CEM	CEM	1629000	kt	2009	USGS, 2012 (2009 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
CHN	China (and Hong Kong if not separately identified)	CSP	CSP-C	81	kt	2010	UNEP, 2012
CHN	China (and Hong Kong if not separately identified)	GP	GP-L	320000	kg	2009	USGS, 2012 (2009 data)
CHN	China (and Hong Kong if not separately identified)	MP	HG-P	1400	t	2009	USGS, 2012 (2010 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	AL-P	16200	kt	2010	USGS, 2012 (2010 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	CU-P	2650000	t	2009	USGS, 2012 (2009 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	CU-S	800000	t	2009	USGS, 2012 (2009 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	PB-P	2480000	t	2009	USGS, 2012 (2010 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	PB-S	1230000	t	2009	USGS, 2012 (2010 data)
CHN	China (and Hong Kong if not separately identified)	NFMP	ZN-T	4280000	t	2009	USGS, 2012 (2010 data)
CHN	China (and Hong Kong if not separately identified)	OR	CO-OR	371094	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	PIP-C	COC-IND	84725	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	PISP	PIP	590218	kt	2010	Worldsteel Association, 2011
CHN	China (and Hong Kong if not separately identified)	SC-DR-coal	HC-DR	146860	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-DR-gas	NG-DR	1194714	TJ	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-DR-oil	CO-DR	172	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-DR-oil	CO-HF-DR	3804	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-DR-oil	CO-LF-DR	109891	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-IND-coal	HC-IND	491737	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-IND-gas	NG-IND	741840	TJ	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-IND-oil	CO-HF-IND	9388	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-IND-oil	CO-IND	2294	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-IND-oil	CO-LF-IND	20553	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-PP-coal	HC-B-PP	1698077	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-PP-gas	NG-PP	1059955	TJ	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-PP-oil	CO-HF-PP	6425	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-PP-oil	CO-LF-PP	6631	kt	2009	IEA-SB
CHN	China (and Hong Kong if not separately identified)	SC-PP-oil	CO-PP	4933	kt	2009	IEA-SB
CIV	Ivory Coast	CEM	CEM	650	kt	2009	USGS, 2012 (2009 data)
CIV	Ivory Coast	GP	GP-L	6573	kg	2009	USGS, 2012 (2009 data)
CIV	Ivory Coast	OR	CO-OR	3208	kt	2009	IEA-SB
CIV	Ivory Coast	SC-DR-gas	NG-DR	11024	TJ	2009	IEA-SB
CIV	Ivory Coast	SC-DR-oil	CO-HF-DR	8	kt	2009	IEA-SB
CIV	Ivory Coast	SC-DR-oil	CO-LF-DR	409	kt	2009	IEA-SB
CIV	Ivory Coast	SC-IND-oil	CO-HF-IND	19	kt	2009	IEA-SB
CIV	Ivory Coast	SC-IND-oil	CO-LF-IND	103	kt	2009	IEA-SB
CIV	Ivory Coast	SC-PP-gas	NG-PP	50451	TJ	2009	IEA-SB
CIV	Ivory Coast	SC-PP-oil	CO-HF-PP	18	kt	2009	IEA-SB
CIV	Ivory Coast	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
CMR	Cameroon	CEM	CEM	1000	kt	2009	USGS, 2012 (2009 data)
CMR	Cameroon	GP	GP-L	1600	kg	2009	USGS, 2012 (2009 data)
CMR	Cameroon	NFMP	AL-P	76	kt	2010	USGS, 2012 (2010 data)
CMR	Cameroon	OR	CO-OR	1762	kt	2009	IEA-SB
CMR	Cameroon	SC-DR-oil	CO-LF-DR	432	kt	2009	IEA-SB
CMR	Cameroon	SC-IND-oil	CO-HF-IND	87	kt	2009	IEA-SB
CMR	Cameroon	SC-IND-oil	CO-LF-IND	10	kt	2009	IEA-SB
CMR	Cameroon	SC-PP-gas	NG-PP	9572	TJ	2009	IEA-SB
CMR	Cameroon	SC-PP-oil	CO-HF-PP	76	kt	2009	IEA-SB
CMR	Cameroon	SC-PP-oil	CO-LF-PP	236	kt	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	CEM	CEM	444	kt	2009	USGS, 2012 (2009 data)
COD	Dem. Rep. of Congo (Zaire)	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
COD	Dem. Rep. of Congo (Zaire)	PIP-C	COC-IND	30	kt	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	SC-DR-oil	CO-LF-DR	281	kt	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	SC-IND-coal	HC-IND	194	kt	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	SC-IND-oil	CO-HF-IND	42	kt	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	SC-PP-gas	NG-PP	331	TJ	2009	IEA-SB
COD	Dem. Rep. of Congo (Zaire)	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
COG	Congo	CEM	CEM	100	kt	2009	USGS, 2012 (2009 data)
COG	Congo	GP	GP-L	100	kg	2009	USGS, 2012 (2009 data)
COG	Congo	OR	CO-OR	665	kt	2009	IEA-SB
COG	Congo	OR	NGL-OR	20	kt	2009	IEA-SB
COG	Congo	SC-DR-oil	CO-LF-DR	267	kt	2009	IEA-SB
COG	Congo	SC-IND-oil	CO-HF-IND	18	kt	2009	IEA-SB
COG	Congo	SC-PP-gas	NG-PP	2125	TJ	2009	IEA-SB
COL	Columbia	CEM	CEM	10000	kt	2009	USGS, 2012 (2009 data)
COL	Columbia	CSP	CSP-C	22	kt	2010	UNEP, 2012
COL	Columbia	GP	GP-L	47837	kg	2009	USGS, 2012 (2009 data)
COL	Columbia	NFMP	PB-S	10000	t	2009	USGS, 2012 (2009 data)
COL	Columbia	OR	CO-OR	14560	kt	2009	IEA-SB
COL	Columbia	PIP-C	COC-IND	44	kt	2009	IEA-SB
COL	Columbia	PISP	PIP	327	kt	2010	Worldsteel Association, 2011
COL	Columbia	SC-DR-coal	HC-DR	126	kt	2009	IEA-SB
COL	Columbia	SC-DR-gas	NG-DR	74860	TJ	2009	IEA-SB
COL	Columbia	SC-DR-oil	CO-DR	4	kt	2009	IEA-SB
COL	Columbia	SC-DR-oil	CO-LF-DR	4285	kt	2009	IEA-SB
COL	Columbia	SC-IND-coal	HC-IND	2349	kt	2009	IEA-SB
COL	Columbia	SC-IND-gas	NG-IND	80931	TJ	2009	IEA-SB
COL	Columbia	SC-IND-oil	CO-HF-IND	24	kt	2009	IEA-SB
COL	Columbia	SC-IND-oil	CO-IND	108	kt	2009	IEA-SB
COL	Columbia	SC-IND-oil	CO-LF-IND	154	kt	2009	IEA-SB
COL	Columbia	SC-PP-coal	HC-B-PP	1751	kt	2009	IEA-SB
COL	Columbia	SC-PP-gas	NG-PP	190461	TJ	2009	IEA-SB
COL	Columbia	SC-PP-oil	CO-HF-PP	128	kt	2009	IEA-SB
COL	Columbia	SC-PP-oil	CO-LF-PP	63	kt	2009	IEA-SB
COL	Columbia	SC-PP-oil	CO-PP	243	kt	2009	IEA-SB
CRI	Costa Rica	CEM	CEM	2500	kt	2009	USGS, 2012 (2009 data)
CRI	Costa Rica	GP	GP-L	500	kg	2009	USGS, 2012 (2009 data)
CRI	Costa Rica	OR	CO-OR	376	kt	2009	IEA-SB
CRI	Costa Rica	PIP-C	COC-IND	20	kt	2009	IEA-SB
CRI	Costa Rica	SC-DR-oil	CO-HF-DR	8	kt	2009	IEA-SB
CRI	Costa Rica	SC-DR-oil	CO-LF-DR	796	kt	2009	IEA-SB
CRI	Costa Rica	SC-IND-coal	HC-IND	4	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
CRI	Costa Rica	SC-IND-oil	CO-HF-IND	118	kt	2009	IEA-SB
CRI	Costa Rica	SC-IND-oil	CO-LF-IND	68	kt	2009	IEA-SB
CRI	Costa Rica	SC-PP-oil	CO-HF-PP	38	kt	2009	IEA-SB
CRI	Costa Rica	SC-PP-oil	CO-LF-PP	100	kt	2009	IEA-SB
CUB	Cuba	CEM	CEM	1700	kt	2009	USGS, 2012 (2009 data)
CUB	Cuba	CSP	CSP-C	7	kt	2010	UNEP, 2012
CUB	Cuba	OR	CO-OR	5237	kt	2009	IEA-SB
CUB	Cuba	SC-DR-gas	NG-DR	5327	TJ	2009	IEA-SB
CUB	Cuba	SC-DR-oil	CO-HF-DR	61	kt	2009	IEA-SB
CUB	Cuba	SC-DR-oil	CO-LF-DR	640	kt	2009	IEA-SB
CUB	Cuba	SC-IND-coal	HC-IND	17	kt	2009	IEA-SB
CUB	Cuba	SC-IND-gas	NG-IND	11062	TJ	2009	IEA-SB
CUB	Cuba	SC-IND-oil	CO-HF-IND	1030	kt	2009	IEA-SB
CUB	Cuba	SC-IND-oil	CO-IND	1359	kt	2009	IEA-SB
CUB	Cuba	SC-IND-oil	CO-LF-IND	386	kt	2009	IEA-SB
CUB	Cuba	SC-PP-gas	NG-PP	23810	TJ	2009	IEA-SB
CUB	Cuba	SC-PP-oil	CO-HF-PP	1021	kt	2009	IEA-SB
CUB	Cuba	SC-PP-oil	CO-LF-PP	338	kt	2009	IEA-SB
CUB	Cuba	SC-PP-oil	CO-PP	2643	kt	2009	IEA-SB
CYP	Cyprus	CEM	CEM	1800	kt	2009	USGS, 2012 (2009 data)
CYP	Cyprus	SC-DR-coal	BC-DR	1	kt	2009	IEA-SB
CYP	Cyprus	SC-DR-oil	CO-HF-DR	2	kt	2009	IEA-SB
CYP	Cyprus	SC-DR-oil	CO-LF-DR	452	kt	2009	IEA-SB
CYP	Cyprus	SC-IND-coal	HC-IND	21	kt	2009	IEA-SB
CYP	Cyprus	SC-IND-oil	CO-HF-IND	55	kt	2009	IEA-SB
CYP	Cyprus	SC-IND-oil	CO-LF-IND	18	kt	2009	IEA-SB
CYP	Cyprus	SC-PP-oil	CO-HF-PP	1176	kt	2009	IEA-SB
CYP	Cyprus	SC-PP-oil	CO-LF-PP	92	kt	2009	IEA-SB
CZE	Czech Republic	CEM	CEM	3637	kt	2009	USGS, 2012 (2009 data)
CZE	Czech Republic	CSP	CSP-C	196276	t	2010	OSPAR, 2011
CZE	Czech Republic	NFMP	PB-S	29000	t	2009	USGS, 2012 (2010 data)
CZE	Czech Republic	NFMP	ZN-S	0	t	2009	USGS, 2012 (2010 data)
CZE	Czech Republic	OR	CO-OR	7376	kt	2009	IEA-SB
CZE	Czech Republic	PIP-C	COC-IND	432	kt	2009	IEA-SB
CZE	Czech Republic	PISP	PIP	3987	kt	2010	Worldsteel Association, 2011
CZE	Czech Republic	SC-DR-coal	BC-DR	1187	kt	2009	IEA-SB
CZE	Czech Republic	SC-DR-coal	HC-DR	78	kt	2009	IEA-SB
CZE	Czech Republic	SC-DR-gas	NG-DR	162110	TJ	2009	IEA-SB
CZE	Czech Republic	SC-DR-oil	CO-HF-DR	7	kt	2009	IEA-SB
CZE	Czech Republic	SC-DR-oil	CO-LF-DR	3886	kt	2009	IEA-SB
CZE	Czech Republic	SC-IND-coal	BC-IND	2846	kt	2009	IEA-SB
CZE	Czech Republic	SC-IND-coal	HC-IND	955	kt	2009	IEA-SB
CZE	Czech Republic	SC-IND-gas	NG-IND	89307	TJ	2009	IEA-SB
CZE	Czech Republic	SC-IND-oil	CO-HF-IND	140	kt	2009	IEA-SB
CZE	Czech Republic	SC-IND-oil	CO-LF-IND	95	kt	2009	IEA-SB
CZE	Czech Republic	SC-PP-coal	BC-L-PP	37561	kt	2009	IEA-SB
CZE	Czech Republic	SC-PP-coal	HC-B-PP	3540	kt	2009	IEA-SB
CZE	Czech Republic	SC-PP-gas	NG-PP	49786	TJ	2009	IEA-SB
CZE	Czech Republic	SC-PP-oil	CO-HF-PP	169	kt	2009	IEA-SB
CZE	Czech Republic	SC-PP-oil	CO-LF-PP	19	kt	2009	IEA-SB
DEU	Germany	CEM	CEM	30441	kt	2009	USGS, 2012 (2009 data)
DEU	Germany	CSP	CSP-C	878504	t	2010	OSPAR, 2011
DEU	Germany	NFMP	AL-P	394	kt	2010	USGS, 2012 (2010 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
DEU	Germany	NFMP	CU-P	251100	t	2009	USGS, 2012 (2009 data)
DEU	Germany	NFMP	CU-S	282700	t	2009	USGS, 2012 (2009 data)
DEU	Germany	NFMP	PB-P	104900	t	2009	USGS, 2012 (2010 data)
DEU	Germany	NFMP	PB-S	285700	t	2009	USGS, 2012 (2010 data)
DEU	Germany	NFMP	ZN-T	153000	t	2009	USGS, 2012 (2010 data)
DEU	Germany	OR	CO-OR	100903	kt	2009	IEA-SB
DEU	Germany	PIP-C	COC-IND	1233	kt	2009	IEA-SB
DEU	Germany	PISP	PIP	28560	kt	2010	Worldsteel Association, 2011
DEU	Germany	SC-DR-coal	HC-DR	1028	kt	2009	IEA-SB
DEU	Germany	SC-DR-gas	NG-DR	1878149	TJ	2009	IEA-SB
DEU	Germany	SC-DR-oil	CO-LF-DR	46741	kt	2009	IEA-SB
DEU	Germany	SC-IND-coal	BC-IND	350	kt	2009	IEA-SB
DEU	Germany	SC-IND-coal	HC-IND	2385	kt	2009	IEA-SB
DEU	Germany	SC-IND-gas	NG-IND	705392	TJ	2009	IEA-SB
DEU	Germany	SC-IND-oil	CO-HF-IND	823	kt	2009	IEA-SB
DEU	Germany	SC-IND-oil	CO-LF-IND	1621	kt	2009	IEA-SB
DEU	Germany	SC-PP-coal	BC-L-PP	157583	kt	2009	IEA-SB
DEU	Germany	SC-PP-coal	HC-A-PP	2400	kt	2009	IEA-SB
DEU	Germany	SC-PP-coal	HC-B-PP	30199	kt	2009	IEA-SB
DEU	Germany	SC-PP-gas	NG-PP	806025	TJ	2009	IEA-SB
DEU	Germany	SC-PP-oil	CO-HF-PP	1779	kt	2009	IEA-SB
DEU	Germany	SC-PP-oil	CO-LF-PP	495	kt	2009	IEA-SB
DNK	Denmark	CEM	CEM	2000	kt	2009	USGS, 2012 (2009 data)
DNK	Denmark	OR	CO-OR	7805	kt	2009	IEA-SB
DNK	Denmark	PIP-C	COC-IND	25	kt	2009	IEA-SB
DNK	Denmark	SC-DR-coal	HC-DR	50	kt	2009	IEA-SB
DNK	Denmark	SC-DR-gas	NG-DR	41473	TJ	2009	IEA-SB
DNK	Denmark	SC-DR-oil	CO-HF-DR	56	kt	2009	IEA-SB
DNK	Denmark	SC-DR-oil	CO-LF-DR	3483	kt	2009	IEA-SB
DNK	Denmark	SC-IND-coal	HC-IND	127	kt	2009	IEA-SB
DNK	Denmark	SC-IND-gas	NG-IND	30606	TJ	2009	IEA-SB
DNK	Denmark	SC-IND-oil	CO-HF-IND	99	kt	2009	IEA-SB
DNK	Denmark	SC-IND-oil	CO-LF-IND	284	kt	2009	IEA-SB
DNK	Denmark	SC-PP-coal	HC-B-PP	6635	kt	2009	IEA-SB
DNK	Denmark	SC-PP-gas	NG-PP	110843	TJ	2009	IEA-SB
DNK	Denmark	SC-PP-oil	CO-HF-PP	238	kt	2009	IEA-SB
DNK	Denmark	SC-PP-oil	CO-LF-PP	96	kt	2009	IEA-SB
DOM	Dominican Republic	CEM	CEM	3000	kt	2009	USGS, 2012 (2009 data)
DOM	Dominican Republic	GP	GP-L	173	kg	2009	USGS, 2012 (2009 data)
DOM	Dominican Republic	OR	CO-OR	1345	kt	2009	IEA-SB
DOM	Dominican Republic	PIP-C	COC-IND	106	kt	2009	IEA-SB
DOM	Dominican Republic	SC-DR-oil	CO-LF-DR	601	kt	2009	IEA-SB
DOM	Dominican Republic	SC-IND-gas	NG-IND	443	TJ	2009	IEA-SB
DOM	Dominican Republic	SC-IND-oil	CO-HF-IND	228	kt	2009	IEA-SB
DOM	Dominican Republic	SC-IND-oil	CO-LF-IND	122	kt	2009	IEA-SB
DOM	Dominican Republic	SC-PP-coal	HC-B-PP	773	kt	2009	IEA-SB
DOM	Dominican Republic	SC-PP-gas	NG-PP	20173	TJ	2009	IEA-SB
DOM	Dominican Republic	SC-PP-oil	CO-HF-PP	1273	kt	2009	IEA-SB
DOM	Dominican Republic	SC-PP-oil	CO-LF-PP	639	kt	2009	IEA-SB
DZA	Algeria	CEM	CEM	18000	kt	2009	USGS, 2012 (2009 data)
DZA	Algeria	CSP	CSP-C	14	kt	2010	UNEP, 2012
DZA	Algeria	GP	GP-L	1010	kg	2009	USGS, 2012 (2009 data)
DZA	Algeria	NFMP	PB-S	5000	t	2009	USGS, 2012 (2010 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
DZA	Algeria	NFMP	ZN-P	30000	t	2009	USGS, 2012 (2010 data)
DZA	Algeria	OR	CO-OR	22234	kt	2009	IEA-SB
DZA	Algeria	OR	NGL-OR	1306	kt	2009	IEA-SB
DZA	Algeria	PIP-C	COC-IND	118	kt	2009	IEA-SB
DZA	Algeria	PISP	PIP	696	kt	2010	Worldsteel Association, 2011
DZA	Algeria	SC-DR-gas	NG-DR	260360	TJ	2009	IEA-SB
DZA	Algeria	SC-DR-oil	CO-LF-DR	6423	kt	2009	IEA-SB
DZA	Algeria	SC-IND-gas	NG-IND	103459	TJ	2009	IEA-SB
DZA	Algeria	SC-IND-oil	CO-HF-IND	1	kt	2009	IEA-SB
DZA	Algeria	SC-IND-oil	CO-LF-IND	1077	kt	2009	IEA-SB
DZA	Algeria	SC-PP-gas	NG-PP	657613	TJ	2009	IEA-SB
DZA	Algeria	SC-PP-oil	CO-LF-PP	247	kt	2009	IEA-SB
DZA	Algeria	SC-PP-oil	CO-PP	488	kt	2009	IEA-SB
ECU	Ecuador	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
ECU	Ecuador	GP	GP-L	2092	kg	2009	USGS, 2012 (2009 data)
ECU	Ecuador	OR	CO-OR	8776	kt	2009	IEA-SB
ECU	Ecuador	OR	NGL-OR	47	kt	2009	IEA-SB
ECU	Ecuador	SC-DR-oil	CO-LF-DR	2538	kt	2009	IEA-SB
ECU	Ecuador	SC-IND-oil	CO-HF-IND	415	kt	2009	IEA-SB
ECU	Ecuador	SC-IND-oil	CO-LF-IND	640	kt	2009	IEA-SB
ECU	Ecuador	SC-PP-gas	NG-PP	20292	TJ	2009	IEA-SB
ECU	Ecuador	SC-PP-oil	CO-HF-PP	686	kt	2009	IEA-SB
ECU	Ecuador	SC-PP-oil	CO-LF-PP	429	kt	2009	IEA-SB
ECU	Ecuador	SC-PP-oil	CO-PP	494	kt	2009	IEA-SB
EGY	Egypt	CEM	CEM	46500	kt	2009	USGS, 2012 (2009 data)
EGY	Egypt	NFMP	AL-P	266	kt	2010	USGS, 2012 (2010 data)
EGY	Egypt	OR	CO-OR	24684	kt	2009	IEA-SB
EGY	Egypt	OR	NGL-OR	5087	kt	2009	IEA-SB
EGY	Egypt	PIP-C	COC-IND	210	kt	2009	IEA-SB
EGY	Egypt	PISP	PIP	600	kt	2010	Worldsteel Association, 2011
EGY	Egypt	SC-DR-gas	NG-DR	54188	TJ	2009	IEA-SB
EGY	Egypt	SC-DR-oil	CO-HF-DR	553	kt	2009	IEA-SB
EGY	Egypt	SC-DR-oil	CO-LF-DR	8864	kt	2009	IEA-SB
EGY	Egypt	SC-IND-gas	NG-IND	373616	TJ	2009	IEA-SB
EGY	Egypt	SC-IND-oil	CO-HF-IND	548	kt	2009	IEA-SB
EGY	Egypt	SC-IND-oil	CO-LF-IND	1941	kt	2009	IEA-SB
EGY	Egypt	SC-PP-gas	NG-PP	1110702	TJ	2009	IEA-SB
EGY	Egypt	SC-PP-oil	CO-HF-PP	5774	kt	2009	IEA-SB
EGY	Egypt	SC-PP-oil	CO-LF-PP	670	kt	2009	IEA-SB
ERI	Eritrea	CEM	CEM	45	kt	2009	USGS, 2012 (2009 data)
ERI	Eritrea	GP	GP-L	30	kg	2009	USGS, 2012 (2009 data)
ERI	Eritrea	SC-DR-oil	CO-HF-DR	1	kt	2009	IEA-SB
ERI	Eritrea	SC-DR-oil	CO-LF-DR	53	kt	2009	IEA-SB
ERI	Eritrea	SC-IND-oil	CO-HF-IND	7	kt	2009	IEA-SB
ERI	Eritrea	SC-IND-oil	CO-LF-IND	1	kt	2009	IEA-SB
ERI	Eritrea	SC-PP-oil	CO-HF-PP	53	kt	2009	IEA-SB
ERI	Eritrea	SC-PP-oil	CO-LF-PP	11	kt	2009	IEA-SB
ESP	Spain	CEM	CEM	29505	kt	2009	USGS, 2012 (2009 data)
ESP	Spain	CSP	CSP-C	643239	t	2010	OSPAR, 2011
ESP	Spain	GP	GP-L	3450	kg	2009	USGS, 2012 (2009 data)
ESP	Spain	NFMP	AL-P	340	kt	2010	USGS, 2012 (2010 data)
ESP	Spain	NFMP	CU-P	261000	t	2009	USGS, 2012 (2009 data)
ESP	Spain	NFMP	CU-S	4000	t	2009	USGS, 2012 (2009 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
ESP	Spain	NFMP	PB-S	125000	t	2009	USGS, 2012 (2010 data)
ESP	Spain	NFMP	ZN-T	500776	t	2009	USGS, 2012 (2010 data)
ESP	Spain	OR	CO-OR	52651	kt	2009	IEA-SB
ESP	Spain	PIP-C	COC-IND	382	kt	2009	IEA-SB
ESP	Spain	PISP	PIP	3572	kt	2010	Worldsteel Association, 2011
ESP	Spain	SC-DR-coal	HC-DR	450	kt	2009	IEA-SB
ESP	Spain	SC-DR-gas	NG-DR	216464	TJ	2009	IEA-SB
ESP	Spain	SC-DR-oil	CO-HF-DR	430	kt	2009	IEA-SB
ESP	Spain	SC-DR-oil	CO-LF-DR	28785	kt	2009	IEA-SB
ESP	Spain	SC-IND-coal	HC-IND	260	kt	2009	IEA-SB
ESP	Spain	SC-IND-gas	NG-IND	384154	TJ	2009	IEA-SB
ESP	Spain	SC-IND-oil	CO-HF-IND	1005	kt	2009	IEA-SB
ESP	Spain	SC-IND-oil	CO-IND	12	kt	2009	IEA-SB
ESP	Spain	SC-IND-oil	CO-LF-IND	1005	kt	2009	IEA-SB
ESP	Spain	SC-PP-coal	BC-S-PP	1401	kt	2009	IEA-SB
ESP	Spain	SC-PP-coal	HC-A-PP	1602	kt	2009	IEA-SB
ESP	Spain	SC-PP-coal	HC-B-PP	12665	kt	2009	IEA-SB
ESP	Spain	SC-PP-gas	NG-PP	832480	TJ	2009	IEA-SB
ESP	Spain	SC-PP-oil	CO-HF-PP	2561	kt	2009	IEA-SB
ESP	Spain	SC-PP-oil	CO-LF-PP	1123	kt	2009	IEA-SB
EST	Estonia	CEM	CEM	326	kt	2009	USGS, 2012 (2009 data)
EST	Estonia	NFMP	PB-S	10000	t	2009	USGS, 2012 (2010 data)
EST	Estonia	SC-DR-coal	HC-DR	10	kt	2009	IEA-SB
EST	Estonia	SC-DR-gas	NG-DR	3983	TJ	2009	IEA-SB
EST	Estonia	SC-DR-oil	CO-HF-DR	3	kt	2009	IEA-SB
EST	Estonia	SC-DR-oil	CO-LF-DR	486	kt	2009	IEA-SB
EST	Estonia	SC-IND-coal	BC-IND	159	kt	2009	IEA-SB
EST	Estonia	SC-IND-coal	HC-IND	75	kt	2009	IEA-SB
EST	Estonia	SC-IND-gas	NG-IND	4579	TJ	2009	IEA-SB
EST	Estonia	SC-IND-oil	CO-HF-IND	11	kt	2009	IEA-SB
EST	Estonia	SC-IND-oil	CO-LF-IND	41	kt	2009	IEA-SB
EST	Estonia	SC-PP-coal	BC-L-PP	9861	kt	2009	IEA-SB
EST	Estonia	SC-PP-coal	HC-B-PP	2	kt	2009	IEA-SB
EST	Estonia	SC-PP-gas	NG-PP	15268	TJ	2009	IEA-SB
EST	Estonia	SC-PP-oil	CO-HF-PP	61	kt	2009	IEA-SB
EST	Estonia	SC-PP-oil	CO-LF-PP	14	kt	2009	IEA-SB
ETH	Ethiopia	CEM	CEM	2300	kt	2009	USGS, 2012 (2009 data)
ETH	Ethiopia	GP	GP-L	3400	kg	2009	USGS, 2012 (2009 data)
ETH	Ethiopia	SC-DR-oil	CO-LF-DR	1166	kt	2009	IEA-SB
ETH	Ethiopia	SC-IND-oil	CO-HF-IND	162	kt	2009	IEA-SB
ETH	Ethiopia	SC-IND-oil	CO-LF-IND	388	kt	2009	IEA-SB
ETH	Ethiopia	SC-PP-oil	CO-LF-PP	153	kt	2009	IEA-SB
FIN	Finland	CEM	CEM	1750	kt	2009	USGS, 2012 (2009 data)
FIN	Finland	CSP	CSP-C	40000	t	2010	OSPAR, 2011
FIN	Finland	GP	GP-L	7000	kg	2009	USGS, 2012 (2009 data)
FIN	Finland	NFMP	CU-P	137710	t	2009	USGS, 2012 (2009 data)
FIN	Finland	NFMP	CU-S	2000	t	2009	USGS, 2012 (2009 data)
FIN	Finland	NFMP	ZN-P	295049	t	2009	USGS, 2012 (2010 data)
FIN	Finland	OR	CO-OR	10939	kt	2009	IEA-SB
FIN	Finland	OR	NGL-OR	1014	kt	2009	IEA-SB
FIN	Finland	PIP-C	COC-IND	243	kt	2009	IEA-SB
FIN	Finland	PISP	PIP	2564	kt	2010	Worldsteel Association, 2011
FIN	Finland	SC-DR-coal	HC-DR	7	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
FIN	Finland	SC-DR-gas	NG-DR	4264	TJ	2009	IEA-SB
FIN	Finland	SC-DR-oil	CO-HF-DR	201	kt	2009	IEA-SB
FIN	Finland	SC-DR-oil	CO-LF-DR	3514	kt	2009	IEA-SB
FIN	Finland	SC-IND-coal	HC-IND	112	kt	2009	IEA-SB
FIN	Finland	SC-IND-gas	NG-IND	27497	TJ	2009	IEA-SB
FIN	Finland	SC-IND-oil	CO-HF-IND	318	kt	2009	IEA-SB
FIN	Finland	SC-IND-oil	CO-LF-IND	431	kt	2009	IEA-SB
FIN	Finland	SC-PP-coal	HC-B-PP	4459	kt	2009	IEA-SB
FIN	Finland	SC-PP-gas	NG-PP	117759	TJ	2009	IEA-SB
FIN	Finland	SC-PP-oil	CO-HF-PP	454	kt	2009	IEA-SB
FIN	Finland	SC-PP-oil	CO-LF-PP	36	kt	2009	IEA-SB
FJI	Fiji	CEM	CEM	110	kt	2009	USGS, 2012 (2009 data)
FJI	Fiji	GP	GP-L	1040	kg	2009	USGS, 2012 (2009 data)
FRA	France	CEM	CEM	18300	kt	2009	USGS, 2012 (2009 data)
FRA	France	CSP	CSP-C	688610	t	2010	OSPAR, 2011
FRA	France	GP	GP-L	1500	kg	2009	USGS, 2012 (2009 data)
FRA	France	NFMP	AL-P	356	kt	2010	USGS, 2012 (2010 data)
FRA	France	NFMP	PB-P	0	t	2009	USGS, 2012 (2010 data)
FRA	France	NFMP	PB-S	88000	t	2009	USGS, 2012 (2010 data)
FRA	France	NFMP	ZN-P	161000	t	2009	USGS, 2012 (2010 data)
FRA	France	OR	CO-OR	72131	kt	2009	IEA-SB
FRA	France	OR	NGL-OR	35	kt	2009	IEA-SB
FRA	France	PIP-C	COC-IND	1362	kt	2009	IEA-SB
FRA	France	PISP	PIP	10137	kt	2010	Worldsteel Association, 2011
FRA	France	SC-DR-coal	HC-DR	480	kt	2009	IEA-SB
FRA	France	SC-DR-gas	NG-DR	1094061	TJ	2009	IEA-SB
FRA	France	SC-DR-oil	CO-HF-DR	605	kt	2009	IEA-SB
FRA	France	SC-DR-oil	CO-LF-DR	42810	kt	2009	IEA-SB
FRA	France	SC-IND-coal	BC-IND	51	kt	2009	IEA-SB
FRA	France	SC-IND-coal	HC-IND	2006	kt	2009	IEA-SB
FRA	France	SC-IND-gas	NG-IND	307405	TJ	2009	IEA-SB
FRA	France	SC-IND-oil	CO-HF-IND	997	kt	2009	IEA-SB
FRA	France	SC-IND-oil	CO-LF-IND	1448	kt	2009	IEA-SB
FRA	France	SC-PP-coal	HC-B-PP	8119	kt	2009	IEA-SB
FRA	France	SC-PP-gas	NG-PP	306815	TJ	2009	IEA-SB
FRA	France	SC-PP-oil	CO-HF-PP	1650	kt	2009	IEA-SB
FRA	France	SC-PP-oil	CO-LF-PP	136	kt	2009	IEA-SB
GAB	Gabon	CEM	CEM	230	kt	2009	USGS, 2012 (2009 data)
GAB	Gabon	GP	GP-L	300	kg	2009	USGS, 2012 (2009 data)
GAB	Gabon	OR	CO-OR	554	kt	2009	IEA-SB
GAB	Gabon	SC-DR-oil	CO-LF-DR	106	kt	2009	IEA-SB
GAB	Gabon	SC-IND-gas	NG-IND	83	TJ	2009	IEA-SB
GAB	Gabon	SC-IND-oil	CO-HF-IND	34	kt	2009	IEA-SB
GAB	Gabon	SC-IND-oil	CO-LF-IND	146	kt	2009	IEA-SB
GAB	Gabon	SC-PP-gas	NG-PP	6911	TJ	2009	IEA-SB
GAB	Gabon	SC-PP-oil	CO-HF-PP	18	kt	2009	IEA-SB
GAB	Gabon	SC-PP-oil	CO-LF-PP	52	kt	2009	IEA-SB
GBR	United Kingdom	CEM	CEM	7622	kt	2009	USGS, 2012 (2009 data)
GBR	United Kingdom	CSP	CSP-C	277000	t	2010	OSPAR, 2011
GBR	United Kingdom	GP	GP-L	185	kg	2009	USGS, 2012 (2009 data)
GBR	United Kingdom	NFMP	AL-P	186	kt	2010	USGS, 2012 (2010 data)
GBR	United Kingdom	NFMP	PB-P	135000	t	2009	USGS, 2012 (2010 data)
GBR	United Kingdom	NFMP	PB-S	144000	t	2009	USGS, 2012 (2010 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
GBR	United Kingdom	OR	CO-OR	70716	kt	2009	IEA-SB
GBR	United Kingdom	OR	NGL-OR	928	kt	2009	IEA-SB
GBR	United Kingdom	PIP-C	COC-IND	1077	kt	2009	IEA-SB
GBR	United Kingdom	PISP	PIP	7233	kt	2010	Worldsteel Association, 2011
GBR	United Kingdom	SC-DR-coal	HC-DR	771	kt	2009	IEA-SB
GBR	United Kingdom	SC-DR-gas	NG-DR	1504517	TJ	2009	IEA-SB
GBR	United Kingdom	SC-DR-oil	CO-HF-DR	645	kt	2009	IEA-SB
GBR	United Kingdom	SC-DR-oil	CO-LF-DR	22733	kt	2009	IEA-SB
GBR	United Kingdom	SC-IND-coal	HC-IND	1754	kt	2009	IEA-SB
GBR	United Kingdom	SC-IND-gas	NG-IND	412018	TJ	2009	IEA-SB
GBR	United Kingdom	SC-IND-oil	CO-HF-IND	402	kt	2009	IEA-SB
GBR	United Kingdom	SC-IND-oil	CO-LF-IND	2469	kt	2009	IEA-SB
GBR	United Kingdom	SC-PP-coal	HC-B-PP	40148	kt	2009	IEA-SB
GBR	United Kingdom	SC-PP-gas	NG-PP	1619906	TJ	2009	IEA-SB
GBR	United Kingdom	SC-PP-oil	CO-HF-PP	1469	kt	2009	IEA-SB
GBR	United Kingdom	SC-PP-oil	CO-LF-PP	37	kt	2009	IEA-SB
GEO	Georgia	CEM	CEM	450	kt	2009	USGS, 2012 (2009 data)
GEO	Georgia	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
GEO	Georgia	OR	CO-OR	15	kt	2009	IEA-SB
GEO	Georgia	SC-DR-coal	HC-DR	176	kt	2009	IEA-SB
GEO	Georgia	SC-DR-gas	NG-DR	13357	TJ	2009	IEA-SB
GEO	Georgia	SC-DR-oil	CO-LF-DR	314	kt	2009	IEA-SB
GEO	Georgia	SC-IND-coal	HC-IND	50	kt	2009	IEA-SB
GEO	Georgia	SC-IND-gas	NG-IND	8415	TJ	2009	IEA-SB
GEO	Georgia	SC-IND-oil	CO-HF-IND	30	kt	2009	IEA-SB
GEO	Georgia	SC-PP-gas	NG-PP	22652	TJ	2009	IEA-SB
GEO	Georgia	SC-PP-oil	CO-LF-PP	66	kt	2009	IEA-SB
GHA	Ghana	CEM	CEM	1800	kt	2009	USGS, 2012 (2009 data)
GHA	Ghana	GP	GP-L	86000	kg	2009	USGS, 2012 (2009 data)
GHA	Ghana	OR	CO-OR	441	kt	2009	IEA-SB
GHA	Ghana	SC-DR-oil	CO-LF-DR	938	kt	2009	IEA-SB
GHA	Ghana	SC-IND-oil	CO-HF-IND	40	kt	2009	IEA-SB
GHA	Ghana	SC-IND-oil	CO-LF-IND	341	kt	2009	IEA-SB
GHA	Ghana	SC-PP-oil	CO-PP	540	kt	2009	IEA-SB
GIB	Gibraltar	SC-DR-oil	CO-LF-DR	73	kt	2009	IEA-SB
GIB	Gibraltar	SC-PP-oil	CO-HF-PP	42	kt	2009	IEA-SB
GIN	Guinea	CEM	CEM	0.4	Mt	2008	Bilans, 2010
GIN	Guinea	GP	GP-L	18083	kg	2009	USGS, 2012 (2009 data)
GLP	Guadeloupe	CEM	CEM	230	kt	2009	USGS, 2012 (2009 data)
GNQ	Equatorial Guinea	GP	GP-L	200	kg	2009	USGS, 2012 (2009 data)
GRC	Greece	CEM	CEM	16000	kt	2009	USGS, 2012 (2009 data)
GRC	Greece	CSP	CSP-C	39899	t	2010	OSPAR, 2011
GRC	Greece	GP	GP-L	500	kg	2009	USGS, 2012 (2009 data)
GRC	Greece	NFMP	AL-P	130	kt	2010	USGS, 2012 (2010 data)
GRC	Greece	NFMP	PB-S	4000	t	2009	USGS, 2012 (2010 data)
GRC	Greece	OR	CO-OR	17210	kt	2009	IEA-SB
GRC	Greece	PIP-C	COC-IND	1	kt	2009	IEA-SB
GRC	Greece	SC-DR-coal	BC-DR	19	kt	2009	IEA-SB
GRC	Greece	SC-DR-coal	HC-DR	2	kt	2009	IEA-SB
GRC	Greece	SC-DR-gas	NG-DR	19344	TJ	2009	IEA-SB
GRC	Greece	SC-DR-oil	CO-HF-DR	665	kt	2009	IEA-SB
GRC	Greece	SC-DR-oil	CO-LF-DR	5953	kt	2009	IEA-SB
GRC	Greece	SC-IND-coal	BC-IND	29	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
GRC	Greece	SC-IND-coal	HC-IND	261	kt	2009	IEA-SB
GRC	Greece	SC-IND-gas	NG-IND	18988	TJ	2009	IEA-SB
GRC	Greece	SC-IND-oil	CO-HF-IND	427	kt	2009	IEA-SB
GRC	Greece	SC-IND-oil	CO-LF-IND	345	kt	2009	IEA-SB
GRC	Greece	SC-PP-coal	BC-L-PP	65165	kt	2009	IEA-SB
GRC	Greece	SC-PP-coal	HC-B-PP	74	kt	2009	IEA-SB
GRC	Greece	SC-PP-gas	NG-PP	85751	TJ	2009	IEA-SB
GRC	Greece	SC-PP-oil	CO-HF-PP	1769	kt	2009	IEA-SB
GRC	Greece	SC-PP-oil	CO-LF-PP	361	kt	2009	IEA-SB
GTM	Guatemala	CEM	CEM	1500	kt	2009	USGS, 2012 (2009 data)
GTM	Guatemala	GP	GP-L	8485	kg	2009	USGS, 2012 (2009 data)
GTM	Guatemala	OR	CO-OR	91	kt	2009	IEA-SB
GTM	Guatemala	SC-DR-oil	CO-LF-DR	978	kt	2009	IEA-SB
GTM	Guatemala	SC-IND-oil	CO-HF-IND	204	kt	2009	IEA-SB
GTM	Guatemala	SC-IND-oil	CO-LF-IND	96	kt	2009	IEA-SB
GTM	Guatemala	SC-PP-coal	HC-B-PP	294	kt	2009	IEA-SB
GTM	Guatemala	SC-PP-oil	CO-HF-PP	744	kt	2009	IEA-SB
GTM	Guatemala	SC-PP-oil	CO-LF-PP	75	kt	2009	IEA-SB
GUF	French Guiana	CEM	CEM	62	kt	2009	USGS, 2012 (2009 data)
GUF	French Guiana	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
GUY	Guyana	GP	GP-L	8183	kg	2009	USGS, 2012 (2009 data)
HKG	Hong Kong (additional to China)	CEM	CEM	1000	kt	2009	USGS, 2012 (2009 data)
HKG	Hong Kong (additional to China)	SC-DR-oil	CO-LF-DR	1566	kt	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-IND-coal	HC-IND	2155	kt	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-IND-oil	CO-LF-IND	628	kt	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-PP-coal	HC-B-PP	10176	kt	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-PP-gas	NG-PP	101110	TJ	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-PP-oil	CO-HF-PP	29	kt	2009	IEA-SB
HKG	Hong Kong (additional to China)	SC-PP-oil	CO-LF-PP	14	kt	2009	IEA-SB
HND	Honduras	CEM	CEM	1800	kt	2009	USGS, 2012 (2009 data)
HND	Honduras	GP	GP-L	2127	kg	2009	USGS, 2012 (2009 data)
HND	Honduras	SC-DR-oil	CO-HF-DR	30	kt	2009	IEA-SB
HND	Honduras	SC-DR-oil	CO-LF-DR	612	kt	2009	IEA-SB
HND	Honduras	SC-IND-coal	HC-IND	103	kt	2009	IEA-SB
HND	Honduras	SC-IND-oil	CO-HF-IND	180	kt	2009	IEA-SB
HND	Honduras	SC-IND-oil	CO-LF-IND	65	kt	2009	IEA-SB
HND	Honduras	SC-PP-oil	CO-HF-PP	712	kt	2009	IEA-SB
HND	Honduras	SC-PP-oil	CO-LF-PP	23	kt	2009	IEA-SB
HRV	Croatia	CEM	CEM	2800	kt	2009	USGS, 2012 (2009 data)
HRV	Croatia	OR	CO-OR	4695	kt	2009	IEA-SB
HRV	Croatia	OR	NGL-OR	31	kt	2009	IEA-SB
HRV	Croatia	PIP-C	COC-IND	26	kt	2009	IEA-SB
HRV	Croatia	SC-DR-coal	BC-DR	12	kt	2009	IEA-SB
HRV	Croatia	SC-DR-gas	NG-DR	33358	TJ	2009	IEA-SB
HRV	Croatia	SC-DR-oil	CO-HF-DR	22	kt	2009	IEA-SB
HRV	Croatia	SC-DR-oil	CO-LF-DR	1618	kt	2009	IEA-SB
HRV	Croatia	SC-IND-coal	BC-IND	36	kt	2009	IEA-SB
HRV	Croatia	SC-IND-coal	HC-IND	159	kt	2009	IEA-SB
HRV	Croatia	SC-IND-gas	NG-IND	23535	TJ	2009	IEA-SB
HRV	Croatia	SC-IND-oil	CO-HF-IND	88	kt	2009	IEA-SB
HRV	Croatia	SC-IND-oil	CO-LF-IND	166	kt	2009	IEA-SB
HRV	Croatia	SC-PP-coal	BC-L-PP	1	kt	2009	IEA-SB
HRV	Croatia	SC-PP-coal	HC-B-PP	640	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
HRV	Croatia	SC-PP-gas	NG-PP	36966	TJ	2009	IEA-SB
HRV	Croatia	SC-PP-oil	CO-HF-PP	757	kt	2009	IEA-SB
HRV	Croatia	SC-PP-oil	CO-LF-PP	6	kt	2009	IEA-SB
HTI	Haiti	CEM	CEM	300	kt	2009	USGS, 2012 (2009 data)
HTI	Haiti	SC-DR-oil	CO-LF-DR	187	kt	2009	IEA-SB
HTI	Haiti	SC-IND-oil	CO-HF-IND	4	kt	2009	IEA-SB
HTI	Haiti	SC-IND-oil	CO-LF-IND	139	kt	2009	IEA-SB
HTI	Haiti	SC-PP-oil	CO-HF-PP	25	kt	2009	IEA-SB
HTI	Haiti	SC-PP-oil	CO-LF-PP	100	kt	2009	IEA-SB
HUN	Hungary	CEM	CEM	3200	kt	2009	USGS, 2012 (2009 data)
HUN	Hungary	CSP	CSP-C	131000	t	2010	OSPAR, 2011
HUN	Hungary	OR	CO-OR	6324	kt	2009	IEA-SB
HUN	Hungary	OR	NGL-OR	218	kt	2009	IEA-SB
HUN	Hungary	PIP-C	COC-IND	48	kt	2009	IEA-SB
HUN	Hungary	PISP	PIP	1325	kt	2010	Worldsteel Association, 2011
HUN	Hungary	SC-DR-coal	BC-DR	292	kt	2009	IEA-SB
HUN	Hungary	SC-DR-coal	HC-DR	55	kt	2009	IEA-SB
HUN	Hungary	SC-DR-gas	NG-DR	226972	TJ	2009	IEA-SB
HUN	Hungary	SC-DR-oil	CO-HF-DR	2	kt	2009	IEA-SB
HUN	Hungary	SC-DR-oil	CO-LF-DR	2813	kt	2009	IEA-SB
HUN	Hungary	SC-IND-coal	BC-IND	54	kt	2009	IEA-SB
HUN	Hungary	SC-IND-coal	HC-IND	55	kt	2009	IEA-SB
HUN	Hungary	SC-IND-gas	NG-IND	41225	TJ	2009	IEA-SB
HUN	Hungary	SC-IND-oil	CO-HF-IND	13	kt	2009	IEA-SB
HUN	Hungary	SC-IND-oil	CO-LF-IND	30	kt	2009	IEA-SB
HUN	Hungary	SC-PP-coal	BC-L-PP	8757	kt	2009	IEA-SB
HUN	Hungary	SC-PP-coal	BC-S-PP	219	kt	2009	IEA-SB
HUN	Hungary	SC-PP-coal	HC-B-PP	207	kt	2009	IEA-SB
HUN	Hungary	SC-PP-gas	NG-PP	134247	TJ	2009	IEA-SB
HUN	Hungary	SC-PP-oil	CO-HF-PP	210	kt	2009	IEA-SB
HUN	Hungary	SC-PP-oil	CO-LF-PP	52	kt	2009	IEA-SB
IDN	Indonesia	CEM	CEM	40000	kt	2009	USGS, 2012 (2009 data)
IDN	Indonesia	CSP	CSP-C	25	kt	2010	UNEP, 2012
IDN	Indonesia	GP	GP-L	130000	kg	2009	USGS, 2012 (2009 data)
IDN	Indonesia	NFMP	AL-P	252	kt	2010	USGS, 2012 (2010 data)
IDN	Indonesia	NFMP	CU-P	295900	t	2009	USGS, 2012 (2009 data)
IDN	Indonesia	NFMP	PB-S	18000	t	2009	USGS, 2012 (2010 data)
IDN	Indonesia	OR	CO-OR	44608	kt	2009	IEA-SB
IDN	Indonesia	OR	NGL-OR	320	kt	2009	IEA-SB
IDN	Indonesia	SC-DR-gas	NG-DR	5860	TJ	2009	IEA-SB
IDN	Indonesia	SC-DR-oil	CO-HF-DR	205	kt	2009	IEA-SB
IDN	Indonesia	SC-DR-oil	CO-LF-DR	13702	kt	2009	IEA-SB
IDN	Indonesia	SC-IND-coal	BC-IND	19180	kt	2009	IEA-SB
IDN	Indonesia	SC-IND-coal	HC-IND	484	kt	2009	IEA-SB
IDN	Indonesia	SC-IND-gas	NG-IND	570018	TJ	2009	IEA-SB
IDN	Indonesia	SC-IND-oil	CO-HF-IND	1137	kt	2009	IEA-SB
IDN	Indonesia	SC-IND-oil	CO-LF-IND	5190	kt	2009	IEA-SB
IDN	Indonesia	SC-PP-coal	BC-S-PP	33516	kt	2009	IEA-SB
IDN	Indonesia	SC-PP-gas	NG-PP	878042	TJ	2009	IEA-SB
IDN	Indonesia	SC-PP-oil	CO-HF-PP	3544	kt	2009	IEA-SB
IDN	Indonesia	SC-PP-oil	CO-LF-PP	5628	kt	2009	IEA-SB
IND	India	CEM	CEM	205000	kt	2009	USGS, 2012 (2009 data)
IND	India	CSP	CSP-C	188	kt	2010	UNEP, 2012

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
IND	India	GP	GP-L	2800	kg	2009	USGS, 2012 (2009 data)
IND	India	NFMP	AL-P	1450	kt	2010	USGS, 2012 (2010 data)
IND	India	NFMP	CU-P	705100	t	2009	USGS, 2012 (2009 data)
IND	India	NFMP	CU-S	10000	t	2009	USGS, 2012 (2009 data)
IND	India	NFMP	PB-P	62000	t	2009	USGS, 2012 (2010 data)
IND	India	NFMP	PB-S	245000	t	2009	USGS, 2012 (2010 data)
IND	India	NFMP	ZN-T	606100	t	2009	USGS, 2012 (2010 data)
IND	India	OR	CO-OR	186562	kt	2009	IEA-SB
IND	India	OR	NGL-OR	1744	kt	2009	IEA-SB
IND	India	PIP-C	COC-IND	2314	kt	2009	IEA-SB
IND	India	PISP	PIP	38685	kt	2010	Worldsteel Association, 2011
IND	India	SC-DR-coal	HC-DR	54910	kt	2009	IEA-SB
IND	India	SC-DR-gas	NG-DR	100180	TJ	2009	IEA-SB
IND	India	SC-DR-oil	CO-HF-DR	3205	kt	2009	IEA-SB
IND	India	SC-DR-oil	CO-LF-DR	35694	kt	2009	IEA-SB
IND	India	SC-IND-coal	BC-IND	4473	kt	2009	IEA-SB
IND	India	SC-IND-coal	HC-IND	82839	kt	2009	IEA-SB
IND	India	SC-IND-gas	NG-IND	303262	TJ	2009	IEA-SB
IND	India	SC-IND-oil	CO-HF-IND	6809	kt	2009	IEA-SB
IND	India	SC-IND-oil	CO-LF-IND	15299	kt	2009	IEA-SB
IND	India	SC-PP-coal	BC-L-PP	28153	kt	2009	IEA-SB
IND	India	SC-PP-coal	HC-B-PP	394167	kt	2009	IEA-SB
IND	India	SC-PP-gas	NG-PP	1289472	TJ	2009	IEA-SB
IND	India	SC-PP-oil	CO-HF-PP	1444	kt	2009	IEA-SB
IND	India	SC-PP-oil	CO-LF-PP	8272	kt	2009	IEA-SB
IRL	Ireland	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
IRL	Ireland	NFMP	PB-S	19000	t	2009	USGS, 2012 (2010 data)
IRL	Ireland	OR	CO-OR	2812	kt	2009	IEA-SB
IRL	Ireland	SC-DR-coal	BC-DR	25	kt	2009	IEA-SB
IRL	Ireland	SC-DR-coal	HC-DR	319	kt	2009	IEA-SB
IRL	Ireland	SC-DR-gas	NG-DR	48623	TJ	2009	IEA-SB
IRL	Ireland	SC-DR-oil	CO-HF-DR	32	kt	2009	IEA-SB
IRL	Ireland	SC-DR-oil	CO-LF-DR	3180	kt	2009	IEA-SB
IRL	Ireland	SC-IND-coal	HC-IND	168	kt	2009	IEA-SB
IRL	Ireland	SC-IND-gas	NG-IND	24630	TJ	2009	IEA-SB
IRL	Ireland	SC-IND-oil	CO-HF-IND	224	kt	2009	IEA-SB
IRL	Ireland	SC-IND-oil	CO-LF-IND	186	kt	2009	IEA-SB
IRL	Ireland	SC-PP-coal	HC-B-PP	1376	kt	2009	IEA-SB
IRL	Ireland	SC-PP-gas	NG-PP	128079	TJ	2009	IEA-SB
IRL	Ireland	SC-PP-oil	CO-HF-PP	232	kt	2009	IEA-SB
IRL	Ireland	SC-PP-oil	CO-LF-PP	12	kt	2009	IEA-SB
IRN	Iran	CEM	CEM	50000	kt	2009	USGS, 2012 (2009 data)
IRN	Iran	CSP	CSP-C	332	kt	2010	UNEP, 2012
IRN	Iran	GP	GP-L	400	kg	2009	USGS, 2012 (2009 data)
IRN	Iran	NFMP	AL-P	250	kt	2010	USGS, 2012 (2010 data)
IRN	Iran	NFMP	CU-T	260000	t	2009	USGS, 2012 (2009 data)
IRN	Iran	NFMP	PB-P	20000	t	2009	USGS, 2012 (2010 data)
IRN	Iran	NFMP	PB-S	55000	t	2009	USGS, 2012 (2010 data)
IRN	Iran	NFMP	ZN-T	65000	t	2009	USGS, 2012 (2010 data)
IRN	Iran	OR	CO-OR	87818	kt	2009	IEA-SB
IRN	Iran	OR	NGL-OR	1431	kt	2009	IEA-SB
IRN	Iran	PIP-C	COC-IND	188	kt	2009	IEA-SB
IRN	Iran	PISP	PIP	2540	kt	2010	Worldsteel Association, 2011

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
IRN	Iran	SC-DR-coal	HC-DR	14	kt	2009	IEA-SB
IRN	Iran	SC-DR-gas	NG-DR	2019423	TJ	2009	IEA-SB
IRN	Iran	SC-DR-oil	CO-HF-DR	1168	kt	2009	IEA-SB
IRN	Iran	SC-DR-oil	CO-LF-DR	21925	kt	2009	IEA-SB
IRN	Iran	SC-IND-coal	HC-IND	69	kt	2009	IEA-SB
IRN	Iran	SC-IND-gas	NG-IND	993069	TJ	2009	IEA-SB
IRN	Iran	SC-IND-oil	CO-HF-IND	5925	kt	2009	IEA-SB
IRN	Iran	SC-IND-oil	CO-LF-IND	2601	kt	2009	IEA-SB
IRN	Iran	SC-PP	NGL-PP	1398	kt	2009	IEA-SB
IRN	Iran	SC-PP-gas	NG-PP	2106933	TJ	2009	IEA-SB
IRN	Iran	SC-PP-oil	CO-HF-PP	9475	kt	2009	IEA-SB
IRN	Iran	SC-PP-oil	CO-LF-PP	4269	kt	2009	IEA-SB
IRQ	Iraq	CEM	CEM	8000	kt	2009	USGS, 2012 (2009 data)
IRQ	Iraq	CSP	CSP-C	68	kt	2010	UNEP, 2012
IRQ	Iraq	OR	CO-OR	20760	kt	2009	IEA-SB
IRQ	Iraq	SC-DR-oil	CO-LF-DR	5746	kt	2009	IEA-SB
IRQ	Iraq	SC-IND-gas	NG-IND	43662	TJ	2009	IEA-SB
IRQ	Iraq	SC-IND-oil	CO-HF-IND	2851	kt	2009	IEA-SB
IRQ	Iraq	SC-IND-oil	CO-LF-IND	2873	kt	2009	IEA-SB
IRQ	Iraq	SC-PP-oil	CO-HF-PP	7819	kt	2009	IEA-SB
IRQ	Iraq	SC-PP-oil	CO-PP	3439	kt	2009	IEA-SB
ISL	Iceland	CEM	CEM	100	kt	2009	USGS, 2012 (2009 data)
ISL	Iceland	NFMP	AL-P	780	kt	2010	USGS, 2012 (2010 data)
ISL	Iceland	PIP-C	COC-IND	19	kt	2009	IEA-SB
ISL	Iceland	SC-DR-oil	CO-HF-DR	67	kt	2009	IEA-SB
ISL	Iceland	SC-DR-oil	CO-LF-DR	213	kt	2009	IEA-SB
ISL	Iceland	SC-IND-coal	HC-IND	55	kt	2009	IEA-SB
ISL	Iceland	SC-IND-oil	CO-HF-IND	22	kt	2009	IEA-SB
ISL	Iceland	SC-IND-oil	CO-LF-IND	73	kt	2009	IEA-SB
ISL	Iceland	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
ISR	Israel	CEM	CEM	4759	kt	2009	USGS, 2012 (2009 data)
ISR	Israel	CSP	CSP-C	33	kt	2010	UNEP, 2012
ISR	Israel	NFMP	PB-S	22000	t	2009	USGS, 2012 (2010 data)
ISR	Israel	OR	CO-OR	11220	kt	2009	IEA-SB
ISR	Israel	SC-DR-oil	CO-HF-DR	891	kt	2009	IEA-SB
ISR	Israel	SC-DR-oil	CO-LF-DR	2774	kt	2009	IEA-SB
ISR	Israel	SC-IND-gas	NG-IND	7781	TJ	2009	IEA-SB
ISR	Israel	SC-IND-oil	CO-LF-IND	53	kt	2009	IEA-SB
ISR	Israel	SC-PP-coal	BC-L-PP	444	kt	2009	IEA-SB
ISR	Israel	SC-PP-coal	HC-B-PP	12311	kt	2009	IEA-SB
ISR	Israel	SC-PP-gas	NG-PP	159830	TJ	2009	IEA-SB
ISR	Israel	SC-PP-oil	CO-HF-PP	945	kt	2009	IEA-SB
ISR	Israel	SC-PP-oil	CO-LF-PP	203	kt	2009	IEA-SB
ITA	Italy	CEM	CEM	36317	kt	2009	USGS, 2012 (2009 data)
ITA	Italy	CSP	CSP-C	41995	t	2010	OSPAR, 2011
ITA	Italy	GP	GP-L	450	kg	2009	USGS, 2012 (2009 data)
ITA	Italy	NFMP	AL-P	168	kt	2010	USGS, 2012 (2010 data)
ITA	Italy	NFMP	PB-P	15000	t	2009	USGS, 2012 (2010 data)
ITA	Italy	NFMP	PB-S	134000	t	2009	USGS, 2012 (2010 data)
ITA	Italy	NFMP	ZN-T	100000	t	2009	USGS, 2012 (2010 data)
ITA	Italy	OR	CO-OR	80348	kt	2009	IEA-SB
ITA	Italy	PIP-C	COC-IND	1076	kt	2009	IEA-SB
ITA	Italy	PISP	PIP	8555	kt	2010	Worldsteel Association, 2011

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
ITA	Italy	SC-DR-coal	HC-DR	6	kt	2009	IEA-SB
ITA	Italy	SC-DR-gas	NG-DR	1217603	TJ	2009	IEA-SB
ITA	Italy	SC-DR-oil	CO-HF-DR	739	kt	2009	IEA-SB
ITA	Italy	SC-DR-oil	CO-LF-DR	27410	kt	2009	IEA-SB
ITA	Italy	SC-IND-coal	BC-IND	7	kt	2009	IEA-SB
ITA	Italy	SC-IND-coal	HC-IND	398	kt	2009	IEA-SB
ITA	Italy	SC-IND-gas	NG-IND	460411	TJ	2009	IEA-SB
ITA	Italy	SC-IND-oil	CO-HF-IND	1588	kt	2009	IEA-SB
ITA	Italy	SC-IND-oil	CO-LF-IND	320	kt	2009	IEA-SB
ITA	Italy	SC-PP-coal	BC-S-PP	578	kt	2009	IEA-SB
ITA	Italy	SC-PP-coal	HC-B-PP	14649	kt	2009	IEA-SB
ITA	Italy	SC-PP-gas	NG-PP	1251044	TJ	2009	IEA-SB
ITA	Italy	SC-PP-oil	CO-HF-PP	5416	kt	2009	IEA-SB
ITA	Italy	SC-PP-oil	CO-LF-PP	208	kt	2009	IEA-SB
JAM	Jamaica	CEM	CEM	700	kt	2009	USGS, 2012 (2009 data)
JAM	Jamaica	OR	CO-OR	1190	kt	2009	IEA-SB
JAM	Jamaica	SC-DR-oil	CO-HF-DR	807	kt	2009	IEA-SB
JAM	Jamaica	SC-DR-oil	CO-LF-DR	235	kt	2009	IEA-SB
JAM	Jamaica	SC-IND-oil	CO-HF-IND	21	kt	2009	IEA-SB
JAM	Jamaica	SC-IND-oil	CO-LF-IND	18	kt	2009	IEA-SB
JAM	Jamaica	SC-PP-oil	CO-HF-PP	734	kt	2009	IEA-SB
JAM	Jamaica	SC-PP-oil	CO-LF-PP	237	kt	2009	IEA-SB
JOR	Jordan	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
JOR	Jordan	OR	CO-OR	3576	kt	2009	IEA-SB
JOR	Jordan	SC-DR-oil	CO-HF-DR	8	kt	2009	IEA-SB
JOR	Jordan	SC-DR-oil	CO-LF-DR	1035	kt	2009	IEA-SB
JOR	Jordan	SC-IND-oil	CO-HF-IND	290	kt	2009	IEA-SB
JOR	Jordan	SC-IND-oil	CO-LF-IND	544	kt	2009	IEA-SB
JOR	Jordan	SC-PP-gas	NG-PP	143542	TJ	2009	IEA-SB
JOR	Jordan	SC-PP-oil	CO-HF-PP	498	kt	2009	IEA-SB
JOR	Jordan	SC-PP-oil	CO-LF-PP	17	kt	2009	IEA-SB
JPN	Japan	CEM	CEM	54800	kt	2009	USGS, 2012 (2009 data)
JPN	Japan	GP	GP-L	7000	kg	2009	USGS, 2012 (2009 data)
JPN	Japan	NFMP	AL-P	6	kt	2010	USGS, 2012 (2010 data)
JPN	Japan	NFMP	CU-P	1549	kt	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	NFMP	CU-S	0	t	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	NFMP	PB-P	216	kt	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	NFMP	PB-S	51.4	kt	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	NFMP	ZN-P	574	kt	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	NFMP	ZN-S	33.6	kt	2010	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	OR	CO-OR	167623	kt	2009	IEA-SB
JPN	Japan	OR	NGL-OR	9864	kt	2009	IEA-SB
JPN	Japan	PIP-C	COC-IND	9313	kt	2009	IEA-SB
JPN	Japan	PISP	PIP	82283	kt	2010	Worldsteel Association, 2011
JPN	Japan	SC-DR-coal	HC-DR	778	kt	2009	IEA-SB
JPN	Japan	SC-DR-gas	NG-DR	1140936	TJ	2009	IEA-SB
JPN	Japan	SC-DR-oil	CO-HF-DR	2507	kt	2009	IEA-SB
JPN	Japan	SC-DR-oil	CO-LF-DR	33028	kt	2009	IEA-SB
JPN	Japan	SC-IND-coal	HC-IND	17053	kt	2010	National information: Suzuki, 2012 (pers. comm.)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
JPN	Japan	SC-IND-gas	NG-IND	344465	TJ	2009	IEA-SB
JPN	Japan	SC-IND-oil	CO-HF-IND	3898	kt	2009	IEA-SB
JPN	Japan	SC-IND-oil	CO-IND	18	kt	2009	IEA-SB
JPN	Japan	SC-IND-oil	CO-LF-IND	7117	kt	2009	IEA-SB
JPN	Japan	SC-PP	NGL-PP	28	kt	2009	IEA-SB
JPN	Japan	SC-PP-coal	HC-B-PP	71710	kt	2009	National information: Suzuki, 2012 (pers. comm.)
JPN	Japan	SC-PP-gas	NG-PP	2566719	TJ	2009	IEA-SB
JPN	Japan	SC-PP-oil	CO-HF-PP	10003	kt	2009	IEA-SB
JPN	Japan	SC-PP-oil	CO-LF-PP	577	kt	2009	IEA-SB
JPN	Japan	SC-PP-oil	CO-PP	3118	kt	2009	IEA-SB
KAZ	Kazakhstan	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
KAZ	Kazakhstan	GP	GP-L	22000	kg	2009	USGS, 2012 (2009 data)
KAZ	Kazakhstan	NFMP	AL-P	227	kt	2010	USGS, 2012 (2010 data)
KAZ	Kazakhstan	NFMP	CU-T	369000	t	2009	USGS, 2012 (2009 data)
KAZ	Kazakhstan	NFMP	PB-T	80994	t	2009	USGS, 2012 (2010 data)
KAZ	Kazakhstan	NFMP	ZN-T	327873	t	2009	USGS, 2012 (2010 data)
KAZ	Kazakhstan	OR	CO-OR	11820	kt	2009	IEA-SB
KAZ	Kazakhstan	OR	NGL-OR	495	kt	2009	IEA-SB
KAZ	Kazakhstan	PIP-C	COC-IND	2620	kt	2009	IEA-SB
KAZ	Kazakhstan	PISP	PIP	522	kt	2010	Worldsteel Association, 2011
KAZ	Kazakhstan	SC-DR-coal	BC-DR	487	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-DR-coal	HC-DR	2015	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-DR-gas	NG-DR	357450	TJ	2009	IEA-SB
KAZ	Kazakhstan	SC-DR-oil	CO-HF-DR	64	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-DR-oil	CO-LF-DR	1617	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-IND-coal	BC-IND	2015	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-IND-coal	HC-IND	3849	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-IND-oil	CO-HF-IND	556	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-IND-oil	CO-LF-IND	1197	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-PP-coal	BC-L-PP	1797	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-PP-coal	HC-B-PP	49254	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-PP-gas	NG-PP	527888	TJ	2009	IEA-SB
KAZ	Kazakhstan	SC-PP-oil	CO-HF-PP	462	kt	2009	IEA-SB
KAZ	Kazakhstan	SC-PP-oil	CO-PP	903	kt	2009	IEA-SB
KEN	Kenya	CEM	CEM	3320	kt	2009	USGS, 2012 (2009 data)
KEN	Kenya	GP	GP-L	300	kg	2009	USGS, 2012 (2009 data)
KEN	Kenya	NFMP	PB-S	500	t	2009	USGS, 2012 (2010 data)
KEN	Kenya	OR	CO-OR	1606	kt	2009	IEA-SB
KEN	Kenya	SC-DR-oil	CO-HF-DR	10	kt	2009	IEA-SB
KEN	Kenya	SC-DR-oil	CO-LF-DR	924	kt	2009	IEA-SB
KEN	Kenya	SC-IND-coal	HC-IND	95	kt	2009	IEA-SB
KEN	Kenya	SC-IND-oil	CO-HF-IND	58	kt	2009	IEA-SB
KEN	Kenya	SC-IND-oil	CO-LF-IND	200	kt	2009	IEA-SB
KEN	Kenya	SC-PP-oil	CO-HF-PP	661	kt	2009	IEA-SB
KEN	Kenya	SC-PP-oil	CO-LF-PP	316	kt	2009	IEA-SB
KGZ	Kyrgystan	CEM	CEM	1100	kt	2009	USGS, 2012 (2009 data)
KGZ	Kyrgystan	GP	GP-L	16950	kg	2009	USGS, 2012 (2009 data)
KGZ	Kyrgystan	MP	HG-P	250	t	2009	USGS, 2012 (2010 data)
KGZ	Kyrgystan	OR	CO-OR	31	kt	2009	IEA-SB
KGZ	Kyrgystan	SC-DR-gas	NG-DR	13491	TJ	2009	IEA-SB
KGZ	Kyrgystan	SC-DR-oil	CO-HF-DR	250	kt	2009	IEA-SB
KGZ	Kyrgystan	SC-DR-oil	CO-LF-DR	550	kt	2009	IEA-SB
KGZ	Kyrgystan	SC-IND-coal	BC-IND	602	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
KGZ	Kyrgystan	SC-IND-coal	HC-IND	584	kt	2009	IEA-SB
KGZ	Kyrgystan	SC-PP-coal	HC-B-PP	302	kt	2009	IEA-SB
KGZ	Kyrgystan	SC-PP-gas	NG-PP	12104	TJ	2009	IEA-SB
KHM	Cambodia	CEM	CEM	774	kt	2009	USGS, 2012 (2009 data)
KHM	Cambodia	SC-DR-oil	CO-HF-DR	3	kt	2009	IEA-SB
KHM	Cambodia	SC-DR-oil	CO-LF-DR	318	kt	2009	IEA-SB
KHM	Cambodia	SC-IND-oil	CO-HF-IND	27	kt	2009	IEA-SB
KHM	Cambodia	SC-IND-oil	CO-LF-IND	27	kt	2009	IEA-SB
KHM	Cambodia	SC-PP-oil	CO-HF-PP	226	kt	2009	IEA-SB
KHM	Cambodia	SC-PP-oil	CO-LF-PP	218	kt	2009	IEA-SB
KOR	Korea- Rep. of	CEM	CEM	47420060	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	NFMP	CU-P	940988	t	2010	Statistics Korea (kostat.go.kr) - cited in Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	NFMP	CU-S	44000	t	2009	USGS, 2012 (2009 data)
KOR	Korea- Rep. of	NFMP	PB-P	479898	t	2010	Statistics Korea (kostat.go.kr) - cited in Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	NFMP	PB-S	60000	t	2009	USGS, 2012 (2010 data)
KOR	Korea- Rep. of	NFMP	ZN-P	815419	t	2010	Statistics Korea (kostat.go.kr) - cited in Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	OR	CO-OR	110043080	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	PIP-C	COC-IND	1867	kt	2009	IEA-SB
KOR	Korea- Rep. of	PISP	PIP	34111	kt	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-DR-coal	HC-DR	1859000	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-DR-gas	NG-DR	581040	TJ	2009	IEA-SB
KOR	Korea- Rep. of	SC-DR-oil	CO-HF-DR	4571943	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-DR-oil	CO-LF-DR	0	kt	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-IND-coal	HC-IND	0	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-IND-gas	NG-IND	262061	TJ	2009	IEA-SB
KOR	Korea- Rep. of	SC-IND-oil	CO-HF-IND	60117964	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-IND-oil	CO-LF-IND	0	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-coal	BC-S-PP	0	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-coal	HC-A-PP	839000	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-coal	HC-B-PP	76402994	t	2009	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-gas	NG-PP	591253	TJ	2009	IEA-SB
KOR	Korea- Rep. of	SC-PP-oil	CO-HF-PP	2712107	t	2009	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-oil	CO-LF-PP	0	t	2010	National information: Seo, 2012. (pers. comm.)
KOR	Korea- Rep. of	SC-PP-oil	CO-PP	0	t	2009	National information: Seo, 2012. (pers. comm.)
KWT	Kuwait	CEM	CEM	2000	kt	2009	USGS, 2012 (2009 data)
KWT	Kuwait	OR	CO-OR	43587	kt	2009	IEA-SB
KWT	Kuwait	SC-DR-oil	CO-LF-DR	1300	kt	2009	IEA-SB
KWT	Kuwait	SC-IND-gas	NG-IND	126069	TJ	2009	IEA-SB
KWT	Kuwait	SC-IND-oil	CO-LF-IND	867	kt	2009	IEA-SB
KWT	Kuwait	SC-PP-gas	NG-PP	344333	TJ	2009	IEA-SB
KWT	Kuwait	SC-PP-oil	CO-HF-PP	8609	kt	2009	IEA-SB
KWT	Kuwait	SC-PP-oil	CO-LF-PP	959	kt	2009	IEA-SB
KWT	Kuwait	SC-PP-oil	CO-PP	2790	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
LAO	Lao Peoples Dem. Rep.	CEM	CEM	400	kt	2009	USGS, 2012 (2009 data)
LAO	Lao Peoples Dem. Rep.	GP	GP-L	5000	kg	2009	USGS, 2012 (2009 data)
LBN	Lebanon	CEM	CEM	5000	kt	2009	USGS, 2012 (2009 data)
LBN	Lebanon	SC-DR-oil	CO-LF-DR	788	kt	2009	IEA-SB
LBN	Lebanon	SC-IND-coal	HC-IND	200	kt	2009	IEA-SB
LBN	Lebanon	SC-IND-oil	CO-HF-IND	170	kt	2009	IEA-SB
LBN	Lebanon	SC-PP-gas	NG-PP	1931	TJ	2009	IEA-SB
LBN	Lebanon	SC-PP-oil	CO-HF-PP	1228	kt	2009	IEA-SB
LBN	Lebanon	SC-PP-oil	CO-LF-PP	1807	kt	2009	IEA-SB
LBR	Liberia	CEM	CEM	95	kt	2009	USGS, 2012 (2009 data)
LBR	Liberia	GP	GP-L	600	kg	2009	USGS, 2012 (2009 data)
LBY	Libyan Arab Jamah	CEM	CEM	6000	kt	2009	USGS, 2012 (2009 data)
LBY	Libyan Arab Jamah	CSP	CSP-C	45	kt	2010	UNEP, 2012
LBY	Libyan Arab Jamah	OR	CO-OR	19251	kt	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-DR-oil	CO-LF-DR	2539	kt	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-IND-gas	NG-IND	46951	TJ	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-IND-oil	CO-HF-IND	423	kt	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-PP-gas	NG-PP	146552	TJ	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-PP-oil	CO-HF-PP	3036	kt	2009	IEA-SB
LBY	Libyan Arab Jamah	SC-PP-oil	CO-LF-PP	3394	kt	2009	IEA-SB
LKA	Sri Lanka	CEM	CEM	1900	kt	2009	USGS, 2012 (2009 data)
LKA	Sri Lanka	OR	CO-OR	2066	kt	2009	IEA-SB
LKA	Sri Lanka	PIP-C	COC-IND	1	kt	2009	IEA-SB
LKA	Sri Lanka	SC-DR-oil	CO-HF-DR	34	kt	2009	IEA-SB
LKA	Sri Lanka	SC-DR-oil	CO-LF-DR	1127	kt	2009	IEA-SB
LKA	Sri Lanka	SC-IND-coal	HC-IND	75	kt	2009	IEA-SB
LKA	Sri Lanka	SC-IND-oil	CO-HF-IND	202	kt	2009	IEA-SB
LKA	Sri Lanka	SC-IND-oil	CO-LF-IND	77	kt	2009	IEA-SB
LKA	Sri Lanka	SC-PP-oil	CO-HF-PP	986	kt	2009	IEA-SB
LKA	Sri Lanka	SC-PP-oil	CO-LF-PP	314	kt	2009	IEA-SB
LTU	Lithuania	CEM	CEM	1100	kt	2009	USGS, 2012 (2009 data)
LTU	Lithuania	OR	CO-OR	8407	kt	2009	IEA-SB
LTU	Lithuania	PIP-C	COC-IND	11	kt	2009	IEA-SB
LTU	Lithuania	SC-DR-coal	HC-DR	34	kt	2009	IEA-SB
LTU	Lithuania	SC-DR-gas	NG-DR	12026	TJ	2009	IEA-SB
LTU	Lithuania	SC-DR-oil	CO-HF-DR	2	kt	2009	IEA-SB
LTU	Lithuania	SC-DR-oil	CO-LF-DR	851	kt	2009	IEA-SB
LTU	Lithuania	SC-IND-coal	HC-IND	64	kt	2009	IEA-SB
LTU	Lithuania	SC-IND-gas	NG-IND	12183	TJ	2009	IEA-SB
LTU	Lithuania	SC-IND-oil	CO-HF-IND	9	kt	2009	IEA-SB
LTU	Lithuania	SC-IND-oil	CO-LF-IND	18	kt	2009	IEA-SB
LTU	Lithuania	SC-PP-coal	HC-A-PP	1	kt	2009	IEA-SB
LTU	Lithuania	SC-PP-coal	HC-B-PP	2	kt	2009	IEA-SB
LTU	Lithuania	SC-PP-gas	NG-PP	50309	TJ	2009	IEA-SB
LTU	Lithuania	SC-PP-oil	CO-HF-PP	349	kt	2009	IEA-SB
LTU	Lithuania	SC-PP-oil	CO-LF-PP	5	kt	2009	IEA-SB
LUX	Luxembourg	CEM	CEM	780	kt	2009	USGS, 2012 (2009 data)
LUX	Luxembourg	PIP-C	COC-IND	1	kt	2009	IEA-SB
LUX	Luxembourg	SC-DR-gas	NG-DR	18133	TJ	2009	IEA-SB
LUX	Luxembourg	SC-DR-oil	CO-LF-DR	1855	kt	2009	IEA-SB
LUX	Luxembourg	SC-IND-coal	HC-IND	104	kt	2009	IEA-SB
LUX	Luxembourg	SC-IND-gas	NG-IND	11284	TJ	2009	IEA-SB
LUX	Luxembourg	SC-IND-oil	CO-HF-IND	3	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
LUX	Luxembourg	SC-PP-gas	NG-PP	22335	TJ	2009	IEA-SB
LUX	Luxembourg	SC-PP-oil	CO-LF-PP	1	kt	2009	IEA-SB
LVA	Latvia	CEM	CEM	300	kt	2009	USGS, 2012 (2009 data)
LVA	Latvia	PIP-C	COC-IND	5	kt	2009	IEA-SB
LVA	Latvia	SC-DR-coal	HC-DR	56	kt	2009	IEA-SB
LVA	Latvia	SC-DR-gas	NG-DR	10241	TJ	2009	IEA-SB
LVA	Latvia	SC-DR-oil	CO-HF-DR	1	kt	2009	IEA-SB
LVA	Latvia	SC-DR-oil	CO-LF-DR	686	kt	2009	IEA-SB
LVA	Latvia	SC-IND-coal	HC-IND	52	kt	2009	IEA-SB
LVA	Latvia	SC-IND-gas	NG-IND	9863	TJ	2009	IEA-SB
LVA	Latvia	SC-IND-oil	CO-HF-IND	8	kt	2009	IEA-SB
LVA	Latvia	SC-IND-oil	CO-LF-IND	36	kt	2009	IEA-SB
LVA	Latvia	SC-PP-coal	HC-B-PP	22	kt	2009	IEA-SB
LVA	Latvia	SC-PP-gas	NG-PP	36275	TJ	2009	IEA-SB
LVA	Latvia	SC-PP-oil	CO-HF-PP	26	kt	2009	IEA-SB
LVA	Latvia	SC-PP-oil	CO-LF-PP	4	kt	2009	IEA-SB
MAR	Morocco	CEM	CEM	12000	kt	2009	USGS, 2012 (2009 data)
MAR	Morocco	CSP	CSP-C	8	kt	2010	UNEP, 2012
MAR	Morocco	GP	GP-L	1200	kg	2009	USGS, 2012 (2009 data)
MAR	Morocco	MP	HG-P	10	t	2009	USGS, 2012 (2010 data)
MAR	Morocco	NFMP	PB-P	45000	t	2009	USGS, 2012 (2010 data)
MAR	Morocco	NFMP	PB-S	3000	t	2009	USGS, 2012 (2010 data)
MAR	Morocco	OR	CO-OR	4643	kt	2009	IEA-SB
MAR	Morocco	PISP	PIP	15	kt	2008	Bilans, 2010
MAR	Morocco	SC-DR-oil	CO-LF-DR	4196	kt	2009	IEA-SB
MAR	Morocco	SC-IND-coal	HC-IND	23	kt	2009	IEA-SB
MAR	Morocco	SC-IND-gas	NG-IND	1724	TJ	2009	IEA-SB
MAR	Morocco	SC-IND-oil	CO-HF-IND	899	kt	2009	IEA-SB
MAR	Morocco	SC-IND-oil	CO-LF-IND	129	kt	2009	IEA-SB
MAR	Morocco	SC-PP-coal	HC-B-PP	4076	kt	2009	IEA-SB
MAR	Morocco	SC-PP-gas	NG-PP	22818	TJ	2009	IEA-SB
MAR	Morocco	SC-PP-oil	CO-HF-PP	884	kt	2009	IEA-SB
MAR	Morocco	SC-PP-oil	CO-LF-PP	105	kt	2009	IEA-SB
MDA	Republic of Moldova	CEM	CEM	700	kt	2009	USGS, 2012 (2009 data)
MDA	Republic of Moldova	SC-DR-coal	HC-DR	115	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-DR-gas	NG-DR	16531	TJ	2009	IEA-SB
MDA	Republic of Moldova	SC-DR-oil	CO-HF-DR	11	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-DR-oil	CO-LF-DR	334	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-IND-coal	HC-IND	57	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-IND-gas	NG-IND	1961	TJ	2009	IEA-SB
MDA	Republic of Moldova	SC-IND-oil	CO-HF-IND	1	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-IND-oil	CO-LF-IND	2	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-PP-coal	HC-A-PP	4	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-PP-gas	NG-PP	48479	TJ	2009	IEA-SB
MDA	Republic of Moldova	SC-PP-oil	CO-HF-PP	25	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
MDA	Republic of Moldova	SC-PP-oil	CO-PP	17	kt	2009	IEA-SB
MDG	Madagascar	CEM	CEM	240	kt	2009	USGS, 2012 (2009 data)
MDG	Madagascar	GP	GP-L	70	kg	2009	USGS, 2012 (2009 data)
MEX	Mexico	CEM	CEM	34500	kt	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	CSP	CSP-C	120	kt	2010	UNEP, 2012
MEX	Mexico	GP	GP-L	72596	kg	2010	National information: Solórzano, 2012. (pers. comm.)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
MEX	Mexico	NFMP	CU-P	237609	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	NFMP	CU-S	5000	t	2009	USGS, 2012 (2009 data)
MEX	Mexico	NFMP	PB-P	158205	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	NFMP	PB-S	110000	t	2009	USGS, 2012 (2010 data)
MEX	Mexico	NFMP	ZN-P	518428	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	OR	CO-OR	69941	kt	2009	IEA-SB
MEX	Mexico	PIP-C	COC-IND	1539	kt	2009	IEA-SB
MEX	Mexico	PISP	PIP	4580	kt	2010	Worldsteel Association, 2011
MEX	Mexico	SC-DR-gas	NG-DR	42256	TJ	2009	IEA-SB
MEX	Mexico	SC-DR-oil	CO-HF-DR	102855	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	SC-DR-oil	CO-LF-DR	16497	kt	2009	IEA-SB
MEX	Mexico	SC-IND-coal	BC-IND	248170	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	SC-IND-gas	NG-IND	383663	TJ	2009	IEA-SB
MEX	Mexico	SC-IND-oil	CO-HF-IND	3155395	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	SC-IND-oil	CO-LF-IND	1321	kt	2009	IEA-SB
MEX	Mexico	SC-PP-coal	BC-S-PP	14694090	t	2010	National information: Solórzano, 2012. (pers. comm.)
MEX	Mexico	SC-PP-gas	NG-PP	1715609	TJ	2009	IEA-SB
MEX	Mexico	SC-PP-oil	CO-HF-PP	9432120	t	2010	National information: Solórzano, 2012. (pers. comm.)
MKD	Macedonia	CEM	CEM	909	kt	2009	USGS, 2012 (2009 data)
MKD	Macedonia	OR	CO-OR	972	kt	2009	IEA-SB
MKD	Macedonia	PIP-C	COC-IND	2	kt	2009	IEA-SB
MKD	Macedonia	SC-DR-coal	BC-DR	10	kt	2009	IEA-SB
MKD	Macedonia	SC-DR-gas	NG-DR	49	TJ	2009	IEA-SB
MKD	Macedonia	SC-DR-oil	CO-HF-DR	8	kt	2009	IEA-SB
MKD	Macedonia	SC-DR-oil	CO-LF-DR	340	kt	2009	IEA-SB
MKD	Macedonia	SC-IND-coal	BC-IND	117	kt	2009	IEA-SB
MKD	Macedonia	SC-IND-coal	HC-IND	5	kt	2009	IEA-SB
MKD	Macedonia	SC-IND-gas	NG-IND	1306	TJ	2009	IEA-SB
MKD	Macedonia	SC-IND-oil	CO-HF-IND	82	kt	2009	IEA-SB
MKD	Macedonia	SC-IND-oil	CO-LF-IND	25	kt	2009	IEA-SB
MKD	Macedonia	SC-PP-coal	BC-L-PP	7348	kt	2009	IEA-SB
MKD	Macedonia	SC-PP-gas	NG-PP	1617	TJ	2009	IEA-SB
MKD	Macedonia	SC-PP-oil	CO-HF-PP	153	kt	2009	IEA-SB
MKD	Macedonia	SC-PP-oil	CO-LF-PP	9	kt	2009	IEA-SB
MLI	Mali	GP	GP-L	42000	kg	2009	USGS, 2012 (2009 data)
MLT	Malta	SC-DR-oil	CO-LF-DR	77	kt	2009	IEA-SB
MLT	Malta	SC-IND-oil	CO-LF-IND	26	kt	2009	IEA-SB
MLT	Malta	SC-PP-oil	CO-HF-PP	523	kt	2009	IEA-SB
MLT	Malta	SC-PP-oil	CO-LF-PP	77	kt	2009	IEA-SB
MMR	Myanmar	CEM	CEM	670	kt	2009	USGS, 2012 (2009 data)
MMR	Myanmar	CSP	CSP-C	7	kt	2010	UNEP, 2012
MMR	Myanmar	GP	GP-L	100	kg	2009	USGS, 2012 (2009 data)
MMR	Myanmar	NFMP	PB-P	200	t	2009	USGS, 2012 (2010 data)
MMR	Myanmar	OR	CO-OR	799	kt	2009	IEA-SB
MMR	Myanmar	PISP	PIP	2	kt	2008	Bilans, 2010
MMR	Myanmar	SC-DR-coal	BC-DR	88	kt	2009	IEA-SB
MMR	Myanmar	SC-DR-gas	NG-DR	55764	TJ	2009	IEA-SB
MMR	Myanmar	SC-DR-oil	CO-HF-DR	42	kt	2009	IEA-SB
MMR	Myanmar	SC-DR-oil	CO-LF-DR	453	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
MMR	Myanmar	SC-IND-coal	BC-IND	29	kt	2009	IEA-SB
MMR	Myanmar	SC-IND-coal	HC-IND	177	kt	2009	IEA-SB
MMR	Myanmar	SC-IND-gas	NG-IND	26561	TJ	2009	IEA-SB
MMR	Myanmar	SC-IND-oil	CO-HF-IND	78	kt	2009	IEA-SB
MMR	Myanmar	SC-IND-oil	CO-LF-IND	87	kt	2009	IEA-SB
MMR	Myanmar	SC-PP-gas	NG-PP	23156	TJ	2009	IEA-SB
MMR	Myanmar	SC-PP-oil	CO-HF-PP	28	kt	2009	IEA-SB
MMR	Myanmar	SC-PP-oil	CO-LF-PP	103	kt	2009	IEA-SB
MNG	Mongolia	CEM	CEM	140	kt	2009	USGS, 2012 (2009 data)
MNG	Mongolia	GP	GP-L	9803	kg	2009	USGS, 2012 (2009 data)
MNG	Mongolia	PIP-C	COC-IND	62	kt	2009	IEA-SB
MNG	Mongolia	SC-DR-coal	BC-DR	1306	kt	2009	IEA-SB
MNG	Mongolia	SC-DR-oil	CO-LF-DR	147	kt	2009	IEA-SB
MNG	Mongolia	SC-IND-coal	BC-IND	226	kt	2009	IEA-SB
MNG	Mongolia	SC-IND-oil	CO-LF-IND	222	kt	2009	IEA-SB
MNG	Mongolia	SC-PP-coal	BC-L-PP	5078	kt	2009	IEA-SB
MNG	Mongolia	SC-PP-oil	CO-HF-PP	5	kt	2009	IEA-SB
MNG	Mongolia	SC-PP-oil	CO-LF-PP	47	kt	2009	IEA-SB
MOZ	Mozambique	CEM	CEM	830	kt	2009	USGS, 2012 (2009 data)
MOZ	Mozambique	GP	GP-L	511	kg	2009	USGS, 2012 (2009 data)
MOZ	Mozambique	NFMP	AL-P	557	kt	2010	USGS, 2012 (2010 data)
MOZ	Mozambique	SC-DR-gas	NG-DR	974	TJ	2009	IEA-SB
MOZ	Mozambique	SC-DR-oil	CO-LF-DR	411	kt	2009	IEA-SB
MOZ	Mozambique	SC-IND-coal	HC-IND	5	kt	2009	IEA-SB
MOZ	Mozambique	SC-IND-gas	NG-IND	2713	TJ	2009	IEA-SB
MOZ	Mozambique	SC-IND-oil	CO-LF-IND	99	kt	2009	IEA-SB
MOZ	Mozambique	SC-PP-coal	HC-B-PP	5	kt	2009	IEA-SB
MOZ	Mozambique	SC-PP-gas	NG-PP	170	TJ	2009	IEA-SB
MRT	Mauritania	CEM	CEM	500	kt	2009	USGS, 2012 (2009 data)
MRT	Mauritania	GP	GP-L	8000	kg	2009	USGS, 2012 (2009 data)
MTQ	Martinique	CEM	CEM	220	kt	2009	USGS, 2012 (2009 data)
MWI	Malawi	CEM	CEM	240	kt	2009	USGS, 2012 (2009 data)
MYS	Malaysia	CEM	CEM	18500	kt	2009	USGS, 2012 (2009 data)
MYS	Malaysia	GP	GP-L	2794	kg	2009	USGS, 2012 (2009 data)
MYS	Malaysia	NFMP	PB-S	70000	t	2009	USGS, 2012 (2010 data)
MYS	Malaysia	OR	CO-OR	25494	kt	2009	IEA-SB
MYS	Malaysia	SC-DR-gas	NG-DR	11012	TJ	2009	IEA-SB
MYS	Malaysia	SC-DR-oil	CO-HF-DR	95	kt	2009	IEA-SB
MYS	Malaysia	SC-DR-oil	CO-LF-DR	5489	kt	2009	IEA-SB
MYS	Malaysia	SC-IND-coal	HC-IND	3009	kt	2009	IEA-SB
MYS	Malaysia	SC-IND-gas	NG-IND	190248	TJ	2009	IEA-SB
MYS	Malaysia	SC-IND-oil	CO-HF-IND	1206	kt	2009	IEA-SB
MYS	Malaysia	SC-IND-oil	CO-LF-IND	3018	kt	2009	IEA-SB
MYS	Malaysia	SC-PP-coal	HC-B-PP	16810	kt	2009	IEA-SB
MYS	Malaysia	SC-PP-gas	NG-PP	932359	TJ	2009	IEA-SB
MYS	Malaysia	SC-PP-oil	CO-HF-PP	207	kt	2009	IEA-SB
MYS	Malaysia	SC-PP-oil	CO-LF-PP	469	kt	2009	IEA-SB
NAM	Namibia	GP	GP-L	2022	kg	2009	USGS, 2012 (2009 data)
NAM	Namibia	NFMP	CU-P	16300	t	2009	USGS, 2012 (2009 data)
NAM	Namibia	NFMP	ZN-T	153815	t	2009	USGS, 2012 (2010 data)
NAM	Namibia	SC-DR-oil	CO-HF-DR	19	kt	2009	IEA-SB
NAM	Namibia	SC-DR-oil	CO-LF-DR	455	kt	2009	IEA-SB
NAM	Namibia	SC-IND-oil	CO-HF-IND	2	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
NAM	Namibia	SC-IND-oil	CO-LF-IND	74	kt	2009	IEA-SB
NAM	Namibia	SC-PP-coal	HC-B-PP	193	kt	2009	IEA-SB
NAM	Namibia	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
NCL	New Caledonia	CEM	CEM	130	kt	2009	USGS, 2012 (2009 data)
NER	Niger	CEM	CEM	40	kt	2009	USGS, 2012 (2009 data)
NER	Niger	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
NGA	Nigeria	CEM	CEM	4500	kt	2009	USGS, 2012 (2009 data)
NGA	Nigeria	GP	GP-L	200	kg	2009	USGS, 2012 (2009 data)
NGA	Nigeria	NFMP	AL-P	21	kt	2010	USGS, 2012 (2010 data)
NGA	Nigeria	NFMP	PB-S	5000	t	2009	USGS, 2012 (2010 data)
NGA	Nigeria	OR	CO-OR	2366	kt	2009	IEA-SB
NGA	Nigeria	SC-DR-oil	CO-LF-DR	631	kt	2009	IEA-SB
NGA	Nigeria	SC-IND-coal	HC-IND	8	kt	2009	IEA-SB
NGA	Nigeria	SC-IND-gas	NG-IND	46150	TJ	2009	IEA-SB
NGA	Nigeria	SC-IND-oil	CO-HF-IND	176	kt	2009	IEA-SB
NGA	Nigeria	SC-IND-oil	CO-LF-IND	23	kt	2009	IEA-SB
NGA	Nigeria	SC-PP-gas	NG-PP	203183	TJ	2009	IEA-SB
NGA	Nigeria	SC-PP-oil	CO-HF-PP	449	kt	2009	IEA-SB
NGA	Nigeria	SC-PP-oil	CO-LF-PP	310	kt	2009	IEA-SB
NIC	Nicaragua	CEM	CEM	530	kt	2009	USGS, 2012 (2009 data)
NIC	Nicaragua	GP	GP-L	3400	kg	2009	USGS, 2012 (2009 data)
NIC	Nicaragua	OR	CO-OR	822	kt	2009	IEA-SB
NIC	Nicaragua	SC-DR-oil	CO-HF-DR	1	kt	2009	IEA-SB
NIC	Nicaragua	SC-DR-oil	CO-LF-DR	329	kt	2009	IEA-SB
NIC	Nicaragua	SC-IND-oil	CO-HF-IND	45	kt	2009	IEA-SB
NIC	Nicaragua	SC-IND-oil	CO-LF-IND	68	kt	2009	IEA-SB
NIC	Nicaragua	SC-PP-oil	CO-HF-PP	533	kt	2009	IEA-SB
NIC	Nicaragua	SC-PP-oil	CO-LF-PP	20	kt	2009	IEA-SB
NLD	Netherlands	CEM	CEM	2700	kt	2009	USGS, 2012 (2009 data)
NLD	Netherlands	NFMP	AL-P	300	kt	2010	USGS, 2012 (2010 data)
NLD	Netherlands	NFMP	PB-S	17000	t	2009	USGS, 2012 (2010 data)
NLD	Netherlands	NFMP	ZN-P	224000	t	2009	USGS, 2012 (2010 data)
NLD	Netherlands	OR	CO-OR	48424	kt	2009	IEA-SB
NLD	Netherlands	OR	NGL-OR	5929	kt	2009	IEA-SB
NLD	Netherlands	PIP-C	COC-IND	104	kt	2009	IEA-SB
NLD	Netherlands	PISP	PIP	5799	kt	2010	Worldsteel Association, 2011
NLD	Netherlands	SC-DR-coal	BC-DR	6	kt	2009	IEA-SB
NLD	Netherlands	SC-DR-coal	HC-DR	7	kt	2009	IEA-SB
NLD	Netherlands	SC-DR-gas	NG-DR	664227	TJ	2009	IEA-SB
NLD	Netherlands	SC-DR-oil	CO-HF-DR	65	kt	2009	IEA-SB
NLD	Netherlands	SC-DR-oil	CO-LF-DR	7150	kt	2009	IEA-SB
NLD	Netherlands	SC-IND	NGL-IND	1852	kt	2009	IEA-SB
NLD	Netherlands	SC-IND-coal	BC-IND	22	kt	2009	IEA-SB
NLD	Netherlands	SC-IND-coal	HC-IND	36	kt	2009	IEA-SB
NLD	Netherlands	SC-IND-gas	NG-IND	222455	TJ	2009	IEA-SB
NLD	Netherlands	SC-IND-oil	CO-LF-IND	131	kt	2009	IEA-SB
NLD	Netherlands	SC-PP-coal	HC-B-PP	8405	kt	2009	IEA-SB
NLD	Netherlands	SC-PP-gas	NG-PP	653516	TJ	2009	IEA-SB
NLD	Netherlands	SC-PP-oil	CO-HF-PP	64	kt	2009	IEA-SB
NLD	Netherlands	SC-PP-oil	CO-LF-PP	12	kt	2009	IEA-SB
NOR	Norway	CEM	CEM	1650	kt	2009	USGS, 2012 (2009 data)
NOR	Norway	NFMP	AL-P	800	kt	2010	USGS, 2012 (2010 data)
NOR	Norway	NFMP	ZN-P	138973	t	2009	USGS, 2012 (2010 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
NOR	Norway	OR	CO-OR	13829	kt	2009	IEA-SB
NOR	Norway	PIP-C	COC-IND	172	kt	2009	IEA-SB
NOR	Norway	PISP	PIP	100	kt	2010	Worldsteel Association, 2011
NOR	Norway	SC-DR-gas	NG-DR	4125	TJ	2009	IEA-SB
NOR	Norway	SC-DR-oil	CO-HF-DR	110	kt	2009	IEA-SB
NOR	Norway	SC-DR-oil	CO-LF-DR	3560	kt	2009	IEA-SB
NOR	Norway	SC-IND-coal	HC-IND	493	kt	2009	IEA-SB
NOR	Norway	SC-IND-gas	NG-IND	9805	TJ	2009	IEA-SB
NOR	Norway	SC-IND-oil	CO-HF-IND	95	kt	2009	IEA-SB
NOR	Norway	SC-IND-oil	CO-LF-IND	359	kt	2009	IEA-SB
NOR	Norway	SC-PP-coal	HC-B-PP	26	kt	2009	IEA-SB
NOR	Norway	SC-PP-gas	NG-PP	203709	TJ	2009	IEA-SB
NOR	Norway	SC-PP-oil	CO-LF-PP	233	kt	2009	IEA-SB
NPL	Nepal	CEM	CEM	300	kt	2009	USGS, 2012 (2009 data)
NPL	Nepal	SC-DR-coal	HC-DR	1	kt	2009	IEA-SB
NPL	Nepal	SC-DR-oil	CO-LF-DR	496	kt	2009	IEA-SB
NPL	Nepal	SC-IND-coal	HC-IND	321	kt	2009	IEA-SB
NPL	Nepal	SC-IND-oil	CO-LF-IND	7	kt	2009	IEA-SB
NPL	Nepal	SC-PP-oil	CO-HF-PP	4	kt	2009	IEA-SB
NZL	New Zealand	CEM	CEM	1100	kt	2009	USGS, 2012 (2009 data)
NZL	New Zealand	GP	GP-L	13442	kg	2009	USGS, 2012 (2009 data)
NZL	New Zealand	NFMP	AL-P	344	kt	2010	USGS, 2012 (2010 data)
NZL	New Zealand	NFMP	PB-S	13000	t	2009	USGS, 2012 (2010 data)
NZL	New Zealand	OR	CO-OR	4789	kt	2009	IEA-SB
NZL	New Zealand	PISP	PIP	667	kt	2010	Worldsteel Association, 2011
NZL	New Zealand	SC-DR-coal	BC-DR	144	kt	2009	IEA-SB
NZL	New Zealand	SC-DR-coal	HC-DR	29	kt	2009	IEA-SB
NZL	New Zealand	SC-DR-gas	NG-DR	14717	TJ	2009	IEA-SB
NZL	New Zealand	SC-DR-oil	CO-HF-DR	31	kt	2009	IEA-SB
NZL	New Zealand	SC-DR-oil	CO-LF-DR	2124	kt	2009	IEA-SB
NZL	New Zealand	SC-IND-coal	BC-IND	682	kt	2009	IEA-SB
NZL	New Zealand	SC-IND-coal	HC-IND	104	kt	2009	IEA-SB
NZL	New Zealand	SC-IND-gas	NG-IND	40011	TJ	2009	IEA-SB
NZL	New Zealand	SC-IND-oil	CO-HF-IND	11	kt	2009	IEA-SB
NZL	New Zealand	SC-IND-oil	CO-LF-IND	305	kt	2009	IEA-SB
NZL	New Zealand	SC-PP-coal	BC-L-PP	19	kt	2009	IEA-SB
NZL	New Zealand	SC-PP-coal	BC-S-PP	1278	kt	2009	IEA-SB
NZL	New Zealand	SC-PP-gas	NG-PP	82322	TJ	2009	IEA-SB
NZL	New Zealand	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
OMN	Oman	CEM	CEM	4000	kt	2009	USGS, 2012 (2009 data)
OMN	Oman	GP	GP-L	28	kg	2009	USGS, 2012 (2009 data)
OMN	Oman	NFMP	AL-P	367	kt	2010	USGS, 2012 (2010 data)
OMN	Oman	NFMP	CU-P	12000	t	2009	USGS, 2012 (2009 data)
OMN	Oman	OR	CO-OR	10265	kt	2009	IEA-SB
OMN	Oman	SC-DR-gas	NG-DR	7255	TJ	2009	IEA-SB
OMN	Oman	SC-DR-oil	CO-LF-DR	461	kt	2009	IEA-SB
OMN	Oman	SC-IND-gas	NG-IND	15805	TJ	2009	IEA-SB
OMN	Oman	SC-IND-oil	CO-HF-IND	1708	kt	2009	IEA-SB
OMN	Oman	SC-PP-gas	NG-PP	353097	TJ	2009	IEA-SB
OMN	Oman	SC-PP-oil	CO-HF-PP	413	kt	2009	IEA-SB
OMN	Oman	SC-PP-oil	CO-LF-PP	1066	kt	2009	IEA-SB
PAK	Pakistan	CEM	CEM	32000	kt	2009	USGS, 2012 (2009 data)
PAK	Pakistan	CSP	CSP-C	33	kt	2010	UNEP, 2012

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PAK	Pakistan	NFMP	CU-P	17500	t	2009	USGS, 2012 (2009 data)
PAK	Pakistan	NFMP	PB-S	2900	t	2009	USGS, 2012 (2010 data)
PAK	Pakistan	OR	CO-OR	9868	kt	2009	IEA-SB
PAK	Pakistan	PIP-C	COC-IND	60	kt	2009	IEA-SB
PAK	Pakistan	PISP	PIP	750	kt	2010	Worldsteel Association, 2011
PAK	Pakistan	SC-DR-gas	NG-DR	367549	TJ	2009	IEA-SB
PAK	Pakistan	SC-DR-oil	CO-HF-DR	169	kt	2009	IEA-SB
PAK	Pakistan	SC-DR-oil	CO-LF-DR	6634	kt	2009	IEA-SB
PAK	Pakistan	SC-IND-coal	BC-IND	1200	kt	2009	IEA-SB
PAK	Pakistan	SC-IND-coal	HC-IND	6382	kt	2009	IEA-SB
PAK	Pakistan	SC-IND-gas	NG-IND	372108	TJ	2009	IEA-SB
PAK	Pakistan	SC-IND-oil	CO-HF-IND	466	kt	2009	IEA-SB
PAK	Pakistan	SC-IND-oil	CO-LF-IND	452	kt	2009	IEA-SB
PAK	Pakistan	SC-PP-coal	HC-B-PP	125	kt	2009	IEA-SB
PAK	Pakistan	SC-PP-gas	NG-PP	326981	TJ	2009	IEA-SB
PAK	Pakistan	SC-PP-oil	CO-HF-PP	8725	kt	2009	IEA-SB
PAK	Pakistan	SC-PP-oil	CO-LF-PP	250	kt	2009	IEA-SB
PAN	Panama	CEM	CEM	1050	kt	2009	USGS, 2012 (2009 data)
PAN	Panama	GP	GP-L	800	kg	2009	USGS, 2012 (2009 data)
PAN	Panama	SC-DR-oil	CO-HF-DR	1	kt	2009	IEA-SB
PAN	Panama	SC-DR-oil	CO-LF-DR	467	kt	2009	IEA-SB
PAN	Panama	SC-IND-oil	CO-HF-IND	57	kt	2009	IEA-SB
PAN	Panama	SC-IND-oil	CO-LF-IND	338	kt	2009	IEA-SB
PAN	Panama	SC-PP-oil	CO-HF-PP	557	kt	2009	IEA-SB
PAN	Panama	SC-PP-oil	CO-LF-PP	121	kt	2009	IEA-SB
PER	Peru	CEM	CEM	6862	kt	2009	USGS, 2012 (2009 data)
PER	Peru	CSP	CSP-C	76	kt	2010	UNEP, 2012
PER	Peru	GP	GP-L	182391	kg	2009	USGS, 2012 (2009 data)
PER	Peru	NFMP	CU-P	345500	t	2009	USGS, 2012 (2009 data)
PER	Peru	NFMP	PB-P	26082	t	2009	USGS, 2012 (2010 data)
PER	Peru	NFMP	ZN-P	149494	t	2009	USGS, 2012 (2010 data)
PER	Peru	OR	CO-OR	9380	kt	2009	IEA-SB
PER	Peru	PIP-C	COC-IND	48	kt	2009	IEA-SB
PER	Peru	PISP	PIP	412	kt	2008	Worldsteel Association, 2011
PER	Peru	SC-DR-gas	NG-DR	15218	TJ	2009	IEA-SB
PER	Peru	SC-DR-oil	CO-HF-DR	187	kt	2009	IEA-SB
PER	Peru	SC-DR-oil	CO-LF-DR	3327	kt	2009	IEA-SB
PER	Peru	SC-IND-coal	HC-IND	783	kt	2009	IEA-SB
PER	Peru	SC-IND-gas	NG-IND	26643	TJ	2009	IEA-SB
PER	Peru	SC-IND-oil	CO-HF-IND	721	kt	2009	IEA-SB
PER	Peru	SC-IND-oil	CO-LF-IND	651	kt	2009	IEA-SB
PER	Peru	SC-PP-coal	HC-B-PP	369	kt	2009	IEA-SB
PER	Peru	SC-PP-gas	NG-PP	148832	TJ	2009	IEA-SB
PER	Peru	SC-PP-oil	CO-HF-PP	431	kt	2009	IEA-SB
PER	Peru	SC-PP-oil	CO-LF-PP	277	kt	2009	IEA-SB
PHL	Philippines	CEM	CEM	14865	kt	2009	USGS, 2012 (2009 data)
PHL	Philippines	CSP	CSP-C	14	kt	2010	UNEP, 2012
PHL	Philippines	GP	GP-L	37047	kg	2009	USGS, 2012 (2009 data)
PHL	Philippines	NFMP	CU-P	230100	t	2009	USGS, 2012 (2009 data)
PHL	Philippines	NFMP	PB-S	40000	t	2009	USGS, 2012 (2010 data)
PHL	Philippines	OR	CO-OR	7007	kt	2009	IEA-SB
PHL	Philippines	PIP-C	COC-IND	11	kt	2009	IEA-SB
PHL	Philippines	SC-DR-oil	CO-HF-DR	420	kt	2009	IEA-SB

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PHL	Philippines	SC-DR-oil	CO-LF-DR	4940	kt	2009	IEA-SB
PHL	Philippines	SC-IND-coal	BC-IND	2783	kt	2009	IEA-SB
PHL	Philippines	SC-IND-gas	NG-IND	3242	TJ	2009	IEA-SB
PHL	Philippines	SC-IND-oil	CO-HF-IND	793	kt	2009	IEA-SB
PHL	Philippines	SC-IND-oil	CO-LF-IND	465	kt	2009	IEA-SB
PHL	Philippines	SC-PP-coal	HC-B-PP	8416	kt	2009	IEA-SB
PHL	Philippines	SC-PP-gas	NG-PP	146237	TJ	2009	IEA-SB
PHL	Philippines	SC-PP-oil	CO-HF-PP	934	kt	2009	IEA-SB
PHL	Philippines	SC-PP-oil	CO-LF-PP	259	kt	2009	IEA-SB
PNG	Papua New Guinea	GP	GP-L	66000	kg	2009	USGS, 2012 (2009 data)
POL	Poland	CEM	CEM	15537	kt	2009	USGS, 2012 (2009 data)
POL	Poland	CSP	CSP-C	125276	t	2010	OSPAR, 2011
POL	Poland	GP	GP-L	814	kg	2009	USGS, 2012 (2009 data)
POL	Poland	NFMP	CU-P	408200	t	2009	USGS, 2012 (2009 data)
POL	Poland	NFMP	CU-S	68800	t	2009	USGS, 2012 (2009 data)
POL	Poland	NFMP	PB-P	30000	t	2009	USGS, 2012 (2010 data)
POL	Poland	NFMP	PB-S	70400	t	2009	USGS, 2012 (2010 data)
POL	Poland	NFMP	ZN-T	139100	t	2009	USGS, 2012 (2010 data)
POL	Poland	OR	CO-OR	20304	kt	2009	IEA-SB
POL	Poland	PIP-C	COC-IND	464	kt	2009	IEA-SB
POL	Poland	PISP	PIP	3638	kt	2010	Worldsteel Association, 2011
POL	Poland	SC-DR-coal	BC-DR	530	kt	2009	IEA-SB
POL	Poland	SC-DR-coal	HC-DR	11807	kt	2009	IEA-SB
POL	Poland	SC-DR-gas	NG-DR	242616	TJ	2009	IEA-SB
POL	Poland	SC-DR-oil	CO-HF-DR	30	kt	2009	IEA-SB
POL	Poland	SC-DR-oil	CO-LF-DR	10967	kt	2009	IEA-SB
POL	Poland	SC-IND-coal	BC-IND	18	kt	2009	IEA-SB
POL	Poland	SC-IND-coal	HC-IND	5341	kt	2009	IEA-SB
POL	Poland	SC-IND-gas	NG-IND	136311	TJ	2009	IEA-SB
POL	Poland	SC-IND-oil	CO-HF-IND	189	kt	2009	IEA-SB
POL	Poland	SC-IND-oil	CO-LF-IND	448	kt	2009	IEA-SB
POL	Poland	SC-PP-coal	BC-L-PP	56159	kt	2009	IEA-SB
POL	Poland	SC-PP-coal	HC-B-PP	47341	kt	2009	IEA-SB
POL	Poland	SC-PP-gas	NG-PP	86665	TJ	2009	IEA-SB
POL	Poland	SC-PP-oil	CO-HF-PP	1271	kt	2009	IEA-SB
POL	Poland	SC-PP-oil	CO-LF-PP	62	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	CEM	CEM	6400	kt	2009	USGS, 2012 (2009 data)
PRK	Korea- Dem. Rep.	CSP	CSP-C	25	kt	2010	UNEP, 2012
PRK	Korea- Dem. Rep.	GP	GP-L	2000	kg	2009	USGS, 2012 (2009 data)
PRK	Korea- Dem. Rep.	NFMP	CU-T	15000	t	2009	USGS, 2012 (2009 data)
PRK	Korea- Dem. Rep.	NFMP	PB-T	9000	t	2009	USGS, 2012 (2010 data)
PRK	Korea- Dem. Rep.	NFMP	ZN-T	75000	t	2009	USGS, 2012 (2010 data)
PRK	Korea- Dem. Rep.	OR	CO-OR	343	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	PIP-C	COC-IND	31	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	PISP	PIP	250	kt	2010	Worldsteel Association, 2011
PRK	Korea- Dem. Rep.	SC-DR-coal	BC-DR	2339	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-DR-coal	HC-DR	3701	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-DR-oil	CO-LF-DR	168	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-IND-coal	BC-IND	3964	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-IND-coal	HC-IND	14316	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-IND-oil	CO-HF-IND	60	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-PP-coal	BC-S-PP	651	kt	2009	IEA-SB
PRK	Korea- Dem. Rep.	SC-PP-coal	HC-B-PP	3605	kt	2009	IEA-SB

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PRK	Korea- Dem. Rep.	SC-PP-oil	CO-HF-PP	277	kt	2009	IEA-SB
PRT	Portugal	CEM	CEM	12700	kt	2009	USGS, 2012 (2009 data)
PRT	Portugal	NFMP	PB-S	3000	t	2009	USGS, 2012 (2010 data)
PRT	Portugal	OR	CO-OR	10406	kt	2009	IEA-SB
PRT	Portugal	PIP-C	COC-IND	3	kt	2009	IEA-SB
PRT	Portugal	PISP	PIP	100	kt	2008	Bilans, 2010
PRT	Portugal	SC-DR-gas	NG-DR	22469	TJ	2009	IEA-SB
PRT	Portugal	SC-DR-oil	CO-HF-DR	165	kt	2009	IEA-SB
PRT	Portugal	SC-DR-oil	CO-LF-DR	4920	kt	2009	IEA-SB
PRT	Portugal	SC-IND-coal	HC-IND	30	kt	2009	IEA-SB
PRT	Portugal	SC-IND-gas	NG-IND	44424	TJ	2009	IEA-SB
PRT	Portugal	SC-IND-oil	CO-HF-IND	314	kt	2009	IEA-SB
PRT	Portugal	SC-IND-oil	CO-LF-IND	264	kt	2009	IEA-SB
PRT	Portugal	SC-PP-coal	HC-B-PP	4638	kt	2009	IEA-SB
PRT	Portugal	SC-PP-gas	NG-PP	124041	TJ	2009	IEA-SB
PRT	Portugal	SC-PP-oil	CO-HF-PP	966	kt	2009	IEA-SB
PRT	Portugal	SC-PP-oil	CO-LF-PP	22	kt	2009	IEA-SB
PRY	Paraguay	CEM	CEM	600	kt	2009	USGS, 2012 (2009 data)
PRY	Paraguay	PISP	PIP	81	kt	2010	Worldsteel Association, 2011
PRY	Paraguay	SC-DR-oil	CO-LF-DR	951	kt	2009	IEA-SB
PRY	Paraguay	SC-IND-oil	CO-HF-IND	28	kt	2009	IEA-SB
QAT	Qatar	CEM	CEM	4150	kt	2009	USGS, 2012 (2009 data)
QAT	Qatar	NFMP	AL-P	190	kt	2010	USGS, 2012 (2010 data)
QAT	Qatar	OR	CO-OR	6344	kt	2009	IEA-SB
QAT	Qatar	SC-DR-oil	CO-LF-DR	1078	kt	2009	IEA-SB
QAT	Qatar	SC-IND-gas	NG-IND	166994	TJ	2009	IEA-SB
QAT	Qatar	SC-PP-gas	NG-PP	615816	TJ	2009	IEA-SB
REU	Reunion	CEM	CEM	375	kt	2009	USGS, 2012 (2009 data)
ROU	Romania	CEM	CEM	7800	kt	2009	USGS, 2012 (2009 data)
ROU	Romania	CSP	CSP-C	186000	t	2010	OSPAR, 2011
ROU	Romania	GP	GP-L	400	kg	2009	USGS, 2012 (2009 data)
ROU	Romania	NFMP	AL-P	207	kt	2010	USGS, 2012 (2010 data)
ROU	Romania	NFMP	PB-P	9000	t	2009	USGS, 2012 (2010 data)
ROU	Romania	NFMP	PB-S	5000	t	2009	USGS, 2012 (2010 data)
ROU	Romania	NFMP	ZN-T	4000	t	2009	USGS, 2012 (2010 data)
ROU	Romania	OR	CO-OR	11210	kt	2009	IEA-SB
ROU	Romania	OR	NGL-OR	110	kt	2009	IEA-SB
ROU	Romania	PIP-C	COC-IND	240	kt	2009	IEA-SB
ROU	Romania	PISP	PIP	1726	kt	2010	Worldsteel Association, 2011
ROU	Romania	SC-DR-coal	BC-DR	74	kt	2009	IEA-SB
ROU	Romania	SC-DR-gas	NG-DR	148495	TJ	2009	IEA-SB
ROU	Romania	SC-DR-oil	CO-HF-DR	21	kt	2009	IEA-SB
ROU	Romania	SC-DR-oil	CO-LF-DR	3451	kt	2009	IEA-SB
ROU	Romania	SC-IND	NGL-IND	13	kt	2009	IEA-SB
ROU	Romania	SC-IND-coal	BC-IND	1080	kt	2009	IEA-SB
ROU	Romania	SC-IND-coal	HC-IND	57	kt	2009	IEA-SB
ROU	Romania	SC-IND-gas	NG-IND	124716	TJ	2009	IEA-SB
ROU	Romania	SC-IND-oil	CO-HF-IND	63	kt	2009	IEA-SB
ROU	Romania	SC-IND-oil	CO-LF-IND	236	kt	2009	IEA-SB
ROU	Romania	SC-PP-coal	BC-L-PP	32208	kt	2009	IEA-SB
ROU	Romania	SC-PP-coal	BC-S-PP	376	kt	2009	IEA-SB
ROU	Romania	SC-PP-gas	NG-PP	168330	TJ	2009	IEA-SB
ROU	Romania	SC-PP-oil	CO-HF-PP	478	kt	2009	IEA-SB

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ROU	Romania	SC-PP-oil	CO-LF-PP	88	kt	2009	IEA-SB
ROU	Romania	SC-PP-oil	CO-PP	3	kt	2009	IEA-SB
RUS	Russia	CEM	CEM	44300	kt	2009	USGS, 2012 (2009 data)
RUS	Russia	CSP	CSP-C	401	kt	2010	UNEP, 2012
RUS	Russia	GP	GP-L	190693	kg	2009	USGS, 2012 (2009 data)
RUS	Russia	MP	HG-P	50	t	2009	USGS, 2012 (2010 data)
RUS	Russia	NFMP	AL-P	3947	kt	2010	USGS, 2012 (2010 data)
RUS	Russia	NFMP	CU-P	580000	t	2009	USGS, 2012 (2009 data)
RUS	Russia	NFMP	CU-S	220000	t	2009	USGS, 2012 (2009 data)
RUS	Russia	NFMP	PB-T	73000	t	2009	USGS, 2012 (2010 data)
RUS	Russia	NFMP	ZN-T	225000	t	2009	USGS, 2012 (2010 data)
RUS	Russia	OR	CO-OR	224577	kt	2009	IEA-SB
RUS	Russia	OR	NGL-OR	14538	kt	2009	IEA-SB
RUS	Russia	PIP-C	COC-IND	646	kt	2009	IEA-SB
RUS	Russia	PISP	PIP	47934	kt	2010	Worldsteel Association, 2011
RUS	Russia	SC-DR-coal	BC-DR	1455	kt	2009	IEA-SB
RUS	Russia	SC-DR-coal	HC-DR	6960	kt	2009	IEA-SB
RUS	Russia	SC-DR-gas	NG-DR	3388326	TJ	2009	IEA-SB
RUS	Russia	SC-DR-oil	CO-DR	28	kt	2009	IEA-SB
RUS	Russia	SC-DR-oil	CO-HF-DR	1413	kt	2009	IEA-SB
RUS	Russia	SC-DR-oil	CO-LF-DR	21677	kt	2009	IEA-SB
RUS	Russia	SC-IND-coal	BC-IND	431	kt	2009	IEA-SB
RUS	Russia	SC-IND-coal	HC-IND	1525	kt	2009	IEA-SB
RUS	Russia	SC-IND-gas	NG-IND	1367953	TJ	2009	IEA-SB
RUS	Russia	SC-IND-oil	CO-HF-IND	1417	kt	2009	IEA-SB
RUS	Russia	SC-IND-oil	CO-IND	13	kt	2009	IEA-SB
RUS	Russia	SC-IND-oil	CO-LF-IND	2284	kt	2009	IEA-SB
RUS	Russia	SC-PP-coal	BC-L-PP	68338	kt	2009	IEA-SB
RUS	Russia	SC-PP-coal	HC-B-PP	74918	kt	2009	IEA-SB
RUS	Russia	SC-PP-gas	NG-PP	10050087	TJ	2009	IEA-SB
RUS	Russia	SC-PP-oil	CO-HF-PP	11468	kt	2009	IEA-SB
RUS	Russia	SC-PP-oil	CO-LF-PP	3909	kt	2009	IEA-SB
RUS	Russia	SC-PP-oil	CO-PP	1011	kt	2009	IEA-SB
RWA	Rwanda	CEM	CEM	100	kt	2009	USGS, 2012 (2009 data)
RWA	Rwanda	GP	GP-L	20	kg	2009	USGS, 2012 (2009 data)
SAU	Saudi Arabia	CEM	CEM	40000	kt	2009	USGS, 2012 (2009 data)
SAU	Saudi Arabia	GP	GP-L	5500	kg	2009	USGS, 2012 (2009 data)
SAU	Saudi Arabia	NFMP	PB-S	38000	t	2009	USGS, 2012 (2010 data)
SAU	Saudi Arabia	OR	CO-OR	87310	kt	2009	IEA-SB
SAU	Saudi Arabia	OR	NGL-OR	8701	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-DR-oil	CO-LF-DR	14569	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-IND-oil	CO-HF-IND	7425	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-IND-oil	CO-IND	4921	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-IND-oil	CO-LF-IND	3129	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-PP-gas	NG-PP	2228419	TJ	2009	IEA-SB
SAU	Saudi Arabia	SC-PP-oil	CO-HF-PP	5078	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-PP-oil	CO-LF-PP	11901	kt	2009	IEA-SB
SAU	Saudi Arabia	SC-PP-oil	CO-PP	16923	kt	2009	IEA-SB
SCG	Serbia and Montenegro	CEM	CEM	2232	kt	2009	USGS, 2012 (2009 data)
SCG	Serbia and Montenegro	CSP	CSP-C	10	kt	2010	UNEP, 2012
SCG	Serbia and Montenegro	GP	GP-L	500	kg	2009	USGS, 2012 (2009 data)
SCG	Serbia and Montenegro	NFMP	AL-P	80	kt	2010	USGS, 2012 (2010 data)
SCG	Serbia and Montenegro	NFMP	CU-P	32000	t	2009	USGS, 2012 (2009 data)

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SCG	Serbia and Montenegro	NFMP	CU-S	1000	t	2009	USGS, 2012 (2009 data)
SCG	Serbia and Montenegro	NFMP	PB-T	900	t	2009	USGS, 2012 (2010 data)
SCG	Serbia and Montenegro	NFMP	ZN-P	5487	t	2009	USGS, 2012 (2010 data)
SCG	Serbia and Montenegro	OR	CO-OR	2880	kt	2009	IEA-SB
SCG	Serbia and Montenegro	OR	NGL-OR	7	kt	2009	IEA-SB
SCG	Serbia and Montenegro	PIP-C	COC-IND	121	kt	2009	IEA-SB
SCG	Serbia and Montenegro	PISP	PIP	1235	kt	2010	Worldsteel Association, 2011
SCG	Serbia and Montenegro	SC-DR-coal	BC-DR	1222	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-DR-gas	NG-DR	14402	TJ	2009	IEA-SB
SCG	Serbia and Montenegro	SC-DR-oil	CO-HF-DR	66	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-DR-oil	CO-LF-DR	1283	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-IND-coal	BC-IND	193	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-IND-coal	HC-IND	14	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-IND-gas	NG-IND	22950	TJ	2009	IEA-SB
SCG	Serbia and Montenegro	SC-IND-oil	CO-HF-IND	77	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-IND-oil	CO-LF-IND	131	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-PP-coal	BC-L-PP	36741	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-PP-coal	BC-S-PP	35	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-PP-gas	NG-PP	23684	TJ	2009	IEA-SB
SCG	Serbia and Montenegro	SC-PP-oil	CO-HF-PP	399	kt	2009	IEA-SB
SCG	Serbia and Montenegro	SC-PP-oil	CO-LF-PP	54	kt	2009	IEA-SB
SDN	Sudan	CEM	CEM	1000	kt	2009	USGS, 2012 (2009 data)
SDN	Sudan	GP	GP-L	1922	kg	2009	USGS, 2012 (2009 data)
SDN	Sudan	OR	CO-OR	4865	kt	2009	IEA-SB
SDN	Sudan	SC-DR-oil	CO-LF-DR	1701	kt	2009	IEA-SB
SDN	Sudan	SC-IND-oil	CO-HF-IND	293	kt	2009	IEA-SB
SDN	Sudan	SC-IND-oil	CO-LF-IND	160	kt	2009	IEA-SB
SDN	Sudan	SC-PP-oil	CO-HF-PP	390	kt	2009	IEA-SB
SDN	Sudan	SC-PP-oil	CO-LF-PP	534	kt	2009	IEA-SB
SEN	Senegal	CEM	CEM	3000	kt	2009	USGS, 2012 (2009 data)
SEN	Senegal	GP	GP-L	5600	kg	2009	USGS, 2012 (2009 data)
SEN	Senegal	OR	CO-OR	744	kt	2009	IEA-SB
SEN	Senegal	SC-DR-oil	CO-LF-DR	497	kt	2009	IEA-SB
SEN	Senegal	SC-IND-coal	HC-IND	254	kt	2009	IEA-SB
SEN	Senegal	SC-IND-oil	CO-HF-IND	62	kt	2009	IEA-SB
SEN	Senegal	SC-IND-oil	CO-LF-IND	35	kt	2009	IEA-SB
SEN	Senegal	SC-PP-gas	NG-PP	677	TJ	2009	IEA-SB
SEN	Senegal	SC-PP-oil	CO-HF-PP	511	kt	2009	IEA-SB
SEN	Senegal	SC-PP-oil	CO-LF-PP	74	kt	2009	IEA-SB
SGP	Singapore	CEM	CEM	0.2	Mt	2008	Bilans, 2010
SGP	Singapore	OR	CO-OR	44130	kt	2009	IEA-SB
SGP	Singapore	SC-DR-gas	NG-DR	10808	TJ	2009	IEA-SB
SGP	Singapore	SC-DR-oil	CO-LF-DR	1733	kt	2009	IEA-SB
SGP	Singapore	SC-IND-gas	NG-IND	18266	TJ	2009	IEA-SB
SGP	Singapore	SC-PP-gas	NG-PP	300969	TJ	2009	IEA-SB
SGP	Singapore	SC-PP-oil	CO-HF-PP	3854	kt	2009	IEA-SB
SGP	Singapore	SC-PP-oil	CO-LF-PP	400	kt	2009	IEA-SB
SLE	Sierra Leone	CEM	CEM	250	kt	2009	USGS, 2012 (2009 data)
SLE	Sierra Leone	GP	GP-L	200	kg	2009	USGS, 2012 (2009 data)
SLV	El Salvador	CEM	CEM	1300	kt	2009	USGS, 2012 (2009 data)
SLV	El Salvador	NFMP	PB-S	10000	t	2009	USGS, 2012 (2009 data)
SLV	El Salvador	OR	CO-OR	844	kt	2009	IEA-SB
SLV	El Salvador	SC-DR-oil	CO-HF-DR	5	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
SLV	El Salvador	SC-DR-oil	CO-LF-DR	379	kt	2009	IEA-SB
SLV	El Salvador	SC-IND-oil	CO-HF-IND	282	kt	2009	IEA-SB
SLV	El Salvador	SC-IND-oil	CO-LF-IND	225	kt	2009	IEA-SB
SLV	El Salvador	SC-PP-oil	CO-HF-PP	591	kt	2009	IEA-SB
SLV	El Salvador	SC-PP-oil	CO-LF-PP	8	kt	2009	IEA-SB
SUR	Suriname	CEM	CEM	65	kt	2009	USGS, 2012 (2009 data)
SUR	Suriname	GP	GP-L	12193	kg	2009	USGS, 2012 (2009 data)
SVK	Slovakia	CEM	CEM	3011	kt	2009	USGS, 2012 (2009 data)
SVK	Slovakia	CSP	CSP-C	76482	t	2010	OSPAR, 2011
SVK	Slovakia	GP	GP-L	200	kg	2009	USGS, 2012 (2009 data)
SVK	Slovakia	NFMP	AL-P	163	kt	2010	USGS, 2012 (2010 data)
SVK	Slovakia	NFMP	CU-S	34200	t	2009	USGS, 2012 (2009 data)
SVK	Slovakia	OR	CO-OR	5700	kt	2009	IEA-SB
SVK	Slovakia	OR	NGL-OR	3	kt	2009	IEA-SB
SVK	Slovakia	PIP-C	COC-IND	69	kt	2009	IEA-SB
SVK	Slovakia	PISP	PIP	3649	kt	2010	Worldsteel Association, 2011
SVK	Slovakia	SC-DR-coal	BC-DR	192	kt	2009	IEA-SB
SVK	Slovakia	SC-DR-coal	HC-DR	607	kt	2009	IEA-SB
SVK	Slovakia	SC-DR-gas	NG-DR	103324	TJ	2009	IEA-SB
SVK	Slovakia	SC-DR-oil	CO-HF-DR	7	kt	2009	IEA-SB
SVK	Slovakia	SC-DR-oil	CO-LF-DR	1119	kt	2009	IEA-SB
SVK	Slovakia	SC-IND-coal	BC-IND	208	kt	2009	IEA-SB
SVK	Slovakia	SC-IND-coal	HC-IND	550	kt	2009	IEA-SB
SVK	Slovakia	SC-IND-gas	NG-IND	35136	TJ	2009	IEA-SB
SVK	Slovakia	SC-IND-oil	CO-HF-IND	50	kt	2009	IEA-SB
SVK	Slovakia	SC-IND-oil	CO-LF-IND	16	kt	2009	IEA-SB
SVK	Slovakia	SC-PP-coal	BC-L-PP	2866	kt	2009	IEA-SB
SVK	Slovakia	SC-PP-coal	HC-A-PP	192	kt	2009	IEA-SB
SVK	Slovakia	SC-PP-coal	HC-B-PP	579	kt	2009	IEA-SB
SVK	Slovakia	SC-PP-gas	NG-PP	47499	TJ	2009	IEA-SB
SVK	Slovakia	SC-PP-oil	CO-HF-PP	264	kt	2009	IEA-SB
SVK	Slovakia	SC-PP-oil	CO-LF-PP	2	kt	2009	IEA-SB
SVN	Slovenia	CEM	CEM	1000	kt	2009	USGS, 2012 (2009 data)
SVN	Slovenia	NFMP	AL-P	40	kt	2010	USGS, 2012 (2010 data)
SVN	Slovenia	NFMP	PB-S	14000	t	2009	USGS, 2012 (2010 data)
SVN	Slovenia	PIP-C	COC-IND	26	kt	2009	IEA-SB
SVN	Slovenia	SC-DR-gas	NG-DR	5778	TJ	2009	IEA-SB
SVN	Slovenia	SC-DR-oil	CO-LF-DR	1557	kt	2009	IEA-SB
SVN	Slovenia	SC-IND-coal	BC-IND	53	kt	2009	IEA-SB
SVN	Slovenia	SC-IND-coal	HC-IND	23	kt	2009	IEA-SB
SVN	Slovenia	SC-IND-gas	NG-IND	20888	TJ	2009	IEA-SB
SVN	Slovenia	SC-IND-oil	CO-HF-IND	16	kt	2009	IEA-SB
SVN	Slovenia	SC-IND-oil	CO-LF-IND	82	kt	2009	IEA-SB
SVN	Slovenia	SC-PP-coal	BC-L-PP	4450	kt	2009	IEA-SB
SVN	Slovenia	SC-PP-coal	BC-S-PP	416	kt	2009	IEA-SB
SVN	Slovenia	SC-PP-gas	NG-PP	7810	TJ	2009	IEA-SB
SVN	Slovenia	SC-PP-oil	CO-HF-PP	4	kt	2009	IEA-SB
SVN	Slovenia	SC-PP-oil	CO-LF-PP	9	kt	2009	IEA-SB
SWE	Sweden	CEM	CEM	2950	kt	2009	USGS, 2012 (2009 data)
SWE	Sweden	CSP	CSP-C	120000	t	2010	OSPAR, 2011
SWE	Sweden	GP	GP-L	5000	kg	2009	USGS, 2012 (2009 data)
SWE	Sweden	NFMP	AL-P	93	kt	2010	USGS, 2012 (2010 data)
SWE	Sweden	NFMP	CU-P	126000	t	2009	USGS, 2012 (2009 data)

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
SWE	Sweden	NFMP	CU-S	39600	t	2009	USGS, 2012 (2009 data)
SWE	Sweden	NFMP	PB-P	26000	t	2009	USGS, 2012 (2010 data)
SWE	Sweden	NFMP	PB-S	40000	t	2009	USGS, 2012 (2010 data)
SWE	Sweden	OR	CO-OR	19638	kt	2009	IEA-SB
SWE	Sweden	PIP-C	COC-IND	102	kt	2009	IEA-SB
SWE	Sweden	PISP	PIP	3447	kt	2010	Worldsteel Association, 2011
SWE	Sweden	SC-DR-gas	NG-DR	7544	TJ	2009	IEA-SB
SWE	Sweden	SC-DR-oil	CO-HF-DR	212	kt	2009	IEA-SB
SWE	Sweden	SC-DR-oil	CO-LF-DR	3986	kt	2009	IEA-SB
SWE	Sweden	SC-IND-coal	HC-IND	386	kt	2009	IEA-SB
SWE	Sweden	SC-IND-gas	NG-IND	18872	TJ	2009	IEA-SB
SWE	Sweden	SC-IND-oil	CO-HF-IND	569	kt	2009	IEA-SB
SWE	Sweden	SC-IND-oil	CO-LF-IND	218	kt	2009	IEA-SB
SWE	Sweden	SC-PP-coal	HC-B-PP	343	kt	2009	IEA-SB
SWE	Sweden	SC-PP-gas	NG-PP	25534	TJ	2009	IEA-SB
SWE	Sweden	SC-PP-oil	CO-HF-PP	258	kt	2009	IEA-SB
SWE	Sweden	SC-PP-oil	CO-LF-PP	91	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	CEM	CEM	5605	kt	2009	USGS, 2012 (2009 data)
SYR	Syrian Arab Rep.	CSP	CSP-C	14	kt	2010	UNEP, 2012
SYR	Syrian Arab Rep.	OR	CO-OR	11681	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-DR-gas	NG-DR	5517	TJ	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-DR-oil	CO-HF-DR	180	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-DR-oil	CO-LF-DR	3347	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-IND-gas	NG-IND	15578	TJ	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-IND-oil	CO-HF-IND	827	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-IND-oil	CO-LF-IND	1803	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-PP-gas	NG-PP	218014	TJ	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-PP-oil	CO-HF-PP	5099	kt	2009	IEA-SB
SYR	Syrian Arab Rep.	SC-PP-oil	CO-LF-PP	616	kt	2009	IEA-SB
TCD	Chad	GP	GP-L	100	kg	2009	USGS, 2012 (2009 data)
TGO	Togo	CEM	CEM	800	kt	2009	USGS, 2012 (2009 data)
TGO	Togo	SC-DR-oil	CO-LF-DR	101	kt	2009	IEA-SB
TGO	Togo	SC-IND-oil	CO-HF-IND	19	kt	2009	IEA-SB
TGO	Togo	SC-IND-oil	CO-LF-IND	2	kt	2009	IEA-SB
TGO	Togo	SC-PP-oil	CO-LF-PP	8	kt	2009	IEA-SB
THA	Thailand	CEM	CEM	31181	kt	2009	USGS, 2012 (2009 data)
THA	Thailand	GP	GP-L	3000	kg	2009	USGS, 2012 (2009 data)
THA	Thailand	NFMP	PB-S	55504	t	2009	USGS, 2012 (2010 data)
THA	Thailand	NFMP	ZN-P	104695	t	2009	USGS, 2012 (2010 data)
THA	Thailand	OR	CO-OR	44251	kt	2009	IEA-SB
THA	Thailand	OR	NGL-OR	1208	kt	2009	IEA-SB
THA	Thailand	PIP-C	COC-IND	2	kt	2009	IEA-SB
THA	Thailand	SC-DR-gas	NG-DR	53666	TJ	2009	IEA-SB
THA	Thailand	SC-DR-oil	CO-HF-DR	4	kt	2009	IEA-SB
THA	Thailand	SC-DR-oil	CO-LF-DR	14503	kt	2009	IEA-SB
THA	Thailand	SC-IND-coal	BC-IND	1995	kt	2009	IEA-SB
THA	Thailand	SC-IND-coal	HC-IND	11106	kt	2009	IEA-SB
THA	Thailand	SC-IND-gas	NG-IND	98331	TJ	2009	IEA-SB
THA	Thailand	SC-IND-oil	CO-HF-IND	980	kt	2009	IEA-SB
THA	Thailand	SC-IND-oil	CO-LF-IND	1021	kt	2009	IEA-SB
THA	Thailand	SC-PP-coal	BC-L-PP	15848	kt	2009	IEA-SB
THA	Thailand	SC-PP-coal	HC-A-PP	466	kt	2009	IEA-SB
THA	Thailand	SC-PP-coal	HC-B-PP	3904	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
THA	Thailand	SC-PP-gas	NG-PP	1087417	TJ	2009	IEA-SB
THA	Thailand	SC-PP-oil	CO-HF-PP	148	kt	2009	IEA-SB
THA	Thailand	SC-PP-oil	CO-LF-PP	22	kt	2009	IEA-SB
TJK	Tajikistan	CEM	CEM	190	kt	2009	USGS, 2012 (2009 data)
TJK	Tajikistan	GP	GP-L	1361	kg	2009	USGS, 2012 (2009 data)
TJK	Tajikistan	MP	HG-P	30	t	2009	USGS, 2012 (2010 data)
TJK	Tajikistan	NFMP	AL-P	349	kt	2010	USGS, 2012 (2010 data)
TJK	Tajikistan	OR	CO-OR	22	kt	2009	IEA-SB
TJK	Tajikistan	SC-DR-coal	BC-DR	23	kt	2009	IEA-SB
TJK	Tajikistan	SC-DR-coal	HC-DR	186	kt	2009	IEA-SB
TJK	Tajikistan	SC-DR-gas	NG-DR	6930	TJ	2009	IEA-SB
TJK	Tajikistan	SC-DR-oil	CO-HF-DR	114	kt	2009	IEA-SB
TJK	Tajikistan	SC-DR-oil	CO-LF-DR	215	kt	2009	IEA-SB
TJK	Tajikistan	SC-PP-gas	NG-PP	9964	TJ	2009	IEA-SB
TKM	Turkmenistan	CEM	CEM	900	kt	2009	USGS, 2012 (2009 data)
TKM	Turkmenistan	CSP	CSP-C	0	kt	2010	UNEP, 2012
TKM	Turkmenistan	OR	CO-OR	7100	kt	2009	IEA-SB
TKM	Turkmenistan	SC-DR-gas	NG-DR	306798	TJ	2009	IEA-SB
TKM	Turkmenistan	SC-DR-oil	CO-HF-DR	1073	kt	2009	IEA-SB
TKM	Turkmenistan	SC-DR-oil	CO-LF-DR	1037	kt	2009	IEA-SB
TKM	Turkmenistan	SC-IND-gas	NG-IND	29308	TJ	2009	IEA-SB
TKM	Turkmenistan	SC-PP	NGL-PP	695	kt	2009	IEA-SB
TKM	Turkmenistan	SC-PP-gas	NG-PP	365133	TJ	2009	IEA-SB
TTO	Trinidad and Tobago	CEM	CEM	950	kt	2009	USGS, 2012 (2009 data)
TTO	Trinidad and Tobago	NFMP	PB-S	1000	t	2009	USGS, 2012 (2009 data)
TTO	Trinidad and Tobago	OR	CO-OR	7805	kt	2009	IEA-SB
TTO	Trinidad and Tobago	SC-DR-gas	NG-DR	8854	TJ	2009	IEA-SB
TTO	Trinidad and Tobago	SC-DR-oil	CO-LF-DR	424	kt	2009	IEA-SB
TTO	Trinidad and Tobago	SC-IND-gas	NG-IND	163970	TJ	2009	IEA-SB
TTO	Trinidad and Tobago	SC-IND-oil	CO-HF-IND	22	kt	2009	IEA-SB
TTO	Trinidad and Tobago	SC-IND-oil	CO-LF-IND	56	kt	2009	IEA-SB
TTO	Trinidad and Tobago	SC-PP-gas	NG-PP	235057	TJ	2009	IEA-SB
TTO	Trinidad and Tobago	SC-PP-oil	CO-LF-PP	30	kt	2009	IEA-SB
TUN	Tunisia	CEM	CEM	8000	kt	2009	USGS, 2012 (2009 data)
TUN	Tunisia	NFMP	PB-S	0	t	2009	USGS, 2012 (2010 data)
TUN	Tunisia	OR	CO-OR	1670	kt	2009	IEA-SB
TUN	Tunisia	SC-DR-gas	NG-DR	15059	TJ	2009	IEA-SB
TUN	Tunisia	SC-DR-oil	CO-HF-DR	26	kt	2009	IEA-SB
TUN	Tunisia	SC-DR-oil	CO-LF-DR	1601	kt	2009	IEA-SB
TUN	Tunisia	SC-IND-gas	NG-IND	41213	TJ	2009	IEA-SB
TUN	Tunisia	SC-IND-oil	CO-HF-IND	80	kt	2009	IEA-SB
TUN	Tunisia	SC-IND-oil	CO-LF-IND	167	kt	2009	IEA-SB
TUN	Tunisia	SC-PP-gas	NG-PP	143752	TJ	2009	IEA-SB
TUN	Tunisia	SC-PP-oil	CO-HF-PP	426	kt	2009	IEA-SB
TUR	Turkey	CEM	CEM	53973	kt	2009	USGS, 2012 (2009 data)
TUR	Turkey	GP	GP-L	12000	kg	2009	USGS, 2012 (2009 data)
TUR	Turkey	NFMP	AL-P	60	kt	2010	USGS, 2012 (2010 data)
TUR	Turkey	NFMP	CU-T	30000	t	2009	USGS, 2012 (2009 data)
TUR	Turkey	NFMP	PB-S	6000	t	2009	USGS, 2012 (2010 data)
TUR	Turkey	OR	CO-OR	18653	kt	2009	IEA-SB
TUR	Turkey	PIP-C	COC-IND	716	kt	2009	IEA-SB
TUR	Turkey	PISP	PIP	7679	kt	2010	Worldsteel Association, 2011
TUR	Turkey	SC-DR-coal	BC-DR	7023	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
TUR	Turkey	SC-DR-coal	HC-DR	5638	kt	2009	IEA-SB
TUR	Turkey	SC-DR-gas	NG-DR	310946	TJ	2009	IEA-SB
TUR	Turkey	SC-DR-oil	CO-HF-DR	427	kt	2009	IEA-SB
TUR	Turkey	SC-DR-oil	CO-LF-DR	12871	kt	2009	IEA-SB
TUR	Turkey	SC-IND-coal	BC-IND	6470	kt	2009	IEA-SB
TUR	Turkey	SC-IND-coal	HC-IND	2953	kt	2009	IEA-SB
TUR	Turkey	SC-IND-gas	NG-IND	204188	TJ	2009	IEA-SB
TUR	Turkey	SC-IND-oil	CO-HF-IND	545	kt	2009	IEA-SB
TUR	Turkey	SC-IND-oil	CO-LF-IND	588	kt	2009	IEA-SB
TUR	Turkey	SC-PP-coal	BC-L-PP	62969	kt	2009	IEA-SB
TUR	Turkey	SC-PP-coal	BC-S-PP	190	kt	2009	IEA-SB
TUR	Turkey	SC-PP-coal	HC-B-PP	5784	kt	2009	IEA-SB
TUR	Turkey	SC-PP-gas	NG-PP	821728	TJ	2009	IEA-SB
TUR	Turkey	SC-PP-oil	CO-HF-PP	1389	kt	2009	IEA-SB
TUR	Turkey	SC-PP-oil	CO-LF-PP	108	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	CEM	CEM	15918	kt	2009	USGS, 2012 (2009 data)
TWN	Taiwan (additional to China)	NFMP	PB-S	40000	t	2009	USGS, 2012 (2010 data)
TWN	Taiwan (additional to China)	OR	CO-OR	47922	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	PIP-C	COC-IND	550	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	PISP	PIP	9358	kt	2010	Worldsteel Association, 2011
TWN	Taiwan (additional to China)	SC-DR-gas	NG-DR	49019	TJ	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-DR-oil	CO-HF-DR	603	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-DR-oil	CO-LF-DR	4206	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-IND-coal	HC-IND	7525	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-IND-gas	NG-IND	35958	TJ	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-IND-oil	CO-HF-IND	3124	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-IND-oil	CO-LF-IND	131	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-PP-coal	BC-S-PP	6072	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-PP-coal	HC-B-PP	40849	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-PP-gas	NG-PP	391621	TJ	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-PP-oil	CO-HF-PP	2455	kt	2009	IEA-SB
TWN	Taiwan (additional to China)	SC-PP-oil	CO-LF-PP	85	kt	2009	IEA-SB
TZA	United Republic of Tanzania	CEM	CEM	1700	kt	2009	USGS, 2012 (2009 data)
TZA	United Republic of Tanzania	GP	GP-L	40000	kg	2009	USGS, 2012 (2009 data)
TZA	United Republic of Tanzania	SC-DR-oil	CO-LF-DR	864	kt	2009	IEA-SB
TZA	United Republic of Tanzania	SC-IND-coal	HC-IND	37	kt	2009	IEA-SB
TZA	United Republic of Tanzania	SC-IND-gas	NG-IND	2916	TJ	2009	IEA-SB
TZA	United Republic of Tanzania	SC-IND-oil	CO-HF-IND	161	kt	2009	IEA-SB
TZA	United Republic of Tanzania	SC-PP-coal	HC-B-PP	58	kt	2009	IEA-SB
TZA	United Republic of Tanzania	SC-PP-gas	NG-PP	22355	TJ	2009	IEA-SB
TZA	United Republic of Tanzania	SC-PP-oil	CO-HF-PP	13	kt	2009	IEA-SB
UGA	Uganda	CEM	CEM	650	kt	2009	USGS, 2012 (2009 data)
UGA	Uganda	GP	GP-L	1600	kg	2009	USGS, 2012 (2009 data)
UKR	Ukraine	CEM	CEM	9496	kt	2009	USGS, 2012 (2009 data)
UKR	Ukraine	NFMP	AL-P	25	kt	2010	USGS, 2012 (2010 data)
UKR	Ukraine	NFMP	PB-S	7000	t	2009	USGS, 2012 (2010 data)
UKR	Ukraine	OR	CO-OR	10204	kt	2009	IEA-SB
UKR	Ukraine	OR	NGL-OR	1059	kt	2009	IEA-SB
UKR	Ukraine	PIP-C	COC-IND	3804	kt	2009	IEA-SB
UKR	Ukraine	PISP	PIP	27349	kt	2010	Worldsteel Association, 2011
UKR	Ukraine	SC-DR-coal	BC-DR	21	kt	2009	IEA-SB
UKR	Ukraine	SC-DR-coal	HC-DR	1605	kt	2009	IEA-SB
UKR	Ukraine	SC-DR-gas	NG-DR	747535	TJ	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
UKR	Ukraine	SC-DR-oil	CO-HF-DR	14	kt	2009	IEA-SB
UKR	Ukraine	SC-DR-oil	CO-LF-DR	3311	kt	2009	IEA-SB
UKR	Ukraine	SC-IND-coal	BC-IND	1	kt	2009	IEA-SB
UKR	Ukraine	SC-IND-coal	HC-IND	1669	kt	2009	IEA-SB
UKR	Ukraine	SC-IND-gas	NG-IND	272573	TJ	2009	IEA-SB
UKR	Ukraine	SC-IND-oil	CO-HF-IND	210	kt	2009	IEA-SB
UKR	Ukraine	SC-IND-oil	CO-LF-IND	889	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-coal	BC-L-PP	6	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-coal	HC-A-PP	5475	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-coal	HC-B-PP	26447	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-gas	NG-PP	840516	TJ	2009	IEA-SB
UKR	Ukraine	SC-PP-oil	CO-HF-PP	448	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-oil	CO-LF-PP	176	kt	2009	IEA-SB
UKR	Ukraine	SC-PP-oil	CO-PP	2	kt	2009	IEA-SB
URY	Uruguay	CEM	CEM	620	kt	2009	USGS, 2012 (2009 data)
URY	Uruguay	CSP	CSP-C	14	kt	2010	UNEP, 2012
URY	Uruguay	GP	GP-L	2180	kg	2009	USGS, 2012 (2009 data)
URY	Uruguay	OR	CO-OR	1967	kt	2009	IEA-SB
URY	Uruguay	SC-DR-gas	NG-DR	1456	TJ	2009	IEA-SB
URY	Uruguay	SC-DR-oil	CO-HF-DR	36	kt	2009	IEA-SB
URY	Uruguay	SC-DR-oil	CO-LF-DR	733	kt	2009	IEA-SB
URY	Uruguay	SC-IND-coal	HC-IND	3	kt	2009	IEA-SB
URY	Uruguay	SC-IND-gas	NG-IND	786	TJ	2009	IEA-SB
URY	Uruguay	SC-IND-oil	CO-HF-IND	123	kt	2009	IEA-SB
URY	Uruguay	SC-IND-oil	CO-LF-IND	28	kt	2009	IEA-SB
URY	Uruguay	SC-PP-gas	NG-PP	275	TJ	2009	IEA-SB
URY	Uruguay	SC-PP-oil	CO-HF-PP	372	kt	2009	IEA-SB
URY	Uruguay	SC-PP-oil	CO-LF-PP	449	kt	2009	IEA-SB
USA	United States	CEM	CEM	64864	kt	2009	USGS, 2012 (2009 data)
USA	United States	CSP	CSP-C	437	kt	2010	UNEP, 2012
USA	United States	GP	GP-L	223000	kg	2009	USGS, 2012 (2009 data)
USA	United States	NFMP	AL-P	1726	kt	2010	USGS, 2012 (2010 data)
USA	United States	NFMP	CU-T	597000	t	2009	USGS, 2012 (2009 data)
USA	United States	NFMP	PB-P	103000	t	2009	USGS, 2012 (2010 data)
USA	United States	NFMP	PB-S	1110000	t	2009	USGS, 2012 (2010 data)
USA	United States	NFMP	ZN-P	94000	t	2009	USGS, 2012 (2010 data)
USA	United States	NFMP	ZN-S	109000	t	2009	USGS, 2012 (2010 data)
USA	United States	OR	CO-OR	726930	kt	2009	IEA-SB
USA	United States	OR	NGL-OR	17105	kt	2009	IEA-SB
USA	United States	PIP-C	COC-IND	2926	kt	2009	IEA-SB
USA	United States	PISP	PIP	26843	kt	2010	Worldsteel Association, 2011
USA	United States	SC-DR-coal	BC-DR	557	kt	2009	IEA-SB
USA	United States	SC-DR-coal	HC-DR	2068	kt	2009	IEA-SB
USA	United States	SC-DR-gas	NG-DR	9182174	TJ	2009	IEA-SB
USA	United States	SC-DR-oil	CO-HF-DR	2873	kt	2009	IEA-SB
USA	United States	SC-DR-oil	CO-LF-DR	152849	kt	2009	IEA-SB
USA	United States	SC-IND-coal	BC-IND	5944	kt	2009	IEA-SB
USA	United States	SC-IND-coal	HC-IND	24176	kt	2009	IEA-SB
USA	United States	SC-IND-gas	NG-IND	4918061	TJ	2009	IEA-SB
USA	United States	SC-IND-oil	CO-HF-IND	3904	kt	2009	IEA-SB
USA	United States	SC-IND-oil	CO-LF-IND	18737	kt	2009	IEA-SB
USA	United States	SC-PP-coal	BC-L-PP	58039	kt	2009	IEA-SB
USA	United States	SC-PP-coal	BC-S-PP	441693	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
USA	United States	SC-PP-coal	HC-A-PP	3467	kt	2009	IEA-SB
USA	United States	SC-PP-coal	HC-B-PP	348589	kt	2009	IEA-SB
USA	United States	SC-PP-gas	NG-PP	10184085	TJ	2009	IEA-SB
USA	United States	SC-PP-oil	CO-HF-PP	4647	kt	2009	IEA-SB
USA	United States	SC-PP-oil	CO-LF-PP	1822	kt	2009	IEA-SB
UZB	Uzbekistan	CEM	CEM	6600	kt	2009	USGS, 2012 (2009 data)
UZB	Uzbekistan	GP	GP-L	90000	kg	2009	USGS, 2012 (2009 data)
UZB	Uzbekistan	NFMP	CU-T	92000	t	2009	USGS, 2012 (2009 data)
UZB	Uzbekistan	NFMP	ZN-P	40000	t	2009	USGS, 2012 (2010 data)
UZB	Uzbekistan	OR	CO-OR	2864	kt	2009	IEA-SB
UZB	Uzbekistan	OR	NGL-OR	1575	kt	2009	IEA-SB
UZB	Uzbekistan	SC-DR-coal	BC-DR	956	kt	2009	IEA-SB
UZB	Uzbekistan	SC-DR-gas	NG-DR	842806	TJ	2009	IEA-SB
UZB	Uzbekistan	SC-DR-oil	CO-HF-DR	2	kt	2009	IEA-SB
UZB	Uzbekistan	SC-DR-oil	CO-LF-DR	1015	kt	2009	IEA-SB
UZB	Uzbekistan	SC-IND-coal	BC-IND	180	kt	2009	IEA-SB
UZB	Uzbekistan	SC-IND-coal	HC-IND	101	kt	2009	IEA-SB
UZB	Uzbekistan	SC-IND-gas	NG-IND	284711	TJ	2009	IEA-SB
UZB	Uzbekistan	SC-IND-oil	CO-HF-IND	1	kt	2009	IEA-SB
UZB	Uzbekistan	SC-IND-oil	CO-LF-IND	109	kt	2009	IEA-SB
UZB	Uzbekistan	SC-PP	NGL-PP	1	kt	2009	IEA-SB
UZB	Uzbekistan	SC-PP-coal	BC-L-PP	2543	kt	2009	IEA-SB
UZB	Uzbekistan	SC-PP-gas	NG-PP	685718	TJ	2009	IEA-SB
UZB	Uzbekistan	SC-PP-oil	CO-HF-PP	333	kt	2009	IEA-SB
UZB	Uzbekistan	SC-PP-oil	CO-LF-PP	1	kt	2009	IEA-SB
UZB	Uzbekistan	SC-PP-oil	CO-PP	8	kt	2009	IEA-SB
VEN	Venezuela	CEM	CEM	9000	kt	2009	USGS, 2012 (2009 data)
VEN	Venezuela	GP	GP-L	10500	kg	2009	USGS, 2012 (2009 data)
VEN	Venezuela	NFMP	AL-P	335	kt	2010	USGS, 2012 (2010 data)
VEN	Venezuela	NFMP	PB-S	30000	t	2009	USGS, 2012 (2010 data)
VEN	Venezuela	OR	CO-OR	58294	kt	2009	IEA-SB
VEN	Venezuela	SC-DR-gas	NG-DR	70046	TJ	2009	IEA-SB
VEN	Venezuela	SC-DR-oil	CO-LF-DR	2925	kt	2009	IEA-SB
VEN	Venezuela	SC-IND-coal	HC-IND	71	kt	2009	IEA-SB
VEN	Venezuela	SC-IND-gas	NG-IND	489960	TJ	2009	IEA-SB
VEN	Venezuela	SC-IND-oil	CO-HF-IND	229	kt	2009	IEA-SB
VEN	Venezuela	SC-IND-oil	CO-LF-IND	2327	kt	2009	IEA-SB
VEN	Venezuela	SC-PP-gas	NG-PP	431356	TJ	2009	IEA-SB
VEN	Venezuela	SC-PP-oil	CO-HF-PP	4028	kt	2009	IEA-SB
VEN	Venezuela	SC-PP-oil	CO-LF-PP	4178	kt	2009	IEA-SB
VNM	Vietnam	CEM	CEM	47900	kt	2009	USGS, 2012 (2009 data)
VNM	Vietnam	GP	GP-L	3000	kg	2009	USGS, 2012 (2009 data)
VNM	Vietnam	NFMP	CU-P	6000	t	2009	USGS, 2012 (2009 data)
VNM	Vietnam	OR	CO-OR	1460	kt	2009	IEA-SB
VNM	Vietnam	PIP-C	COC-IND	89	kt	2009	IEA-SB
VNM	Vietnam	SC-DR-coal	HC-DR	2607	kt	2009	IEA-SB
VNM	Vietnam	SC-DR-oil	CO-HF-DR	118	kt	2009	IEA-SB
VNM	Vietnam	SC-DR-oil	CO-LF-DR	5774	kt	2009	IEA-SB
VNM	Vietnam	SC-IND-coal	HC-IND	13219	kt	2009	IEA-SB
VNM	Vietnam	SC-IND-gas	NG-IND	29713	TJ	2009	IEA-SB
VNM	Vietnam	SC-IND-oil	CO-HF-IND	773	kt	2009	IEA-SB
VNM	Vietnam	SC-IND-oil	CO-LF-IND	1150	kt	2009	IEA-SB
VNM	Vietnam	SC-PP-coal	HC-A-PP	5958	kt	2009	IEA-SB

Country Code	Country Name	Sector Code ¹	Activity Code ¹	Activity Amount	Units	Estimate Year	Reference
VNM	Vietnam	SC-PP-coal	HC-B-PP	613	kt	2009	IEA-SB
VNM	Vietnam	SC-PP-gas	NG-PP	300626	TJ	2009	IEA-SB
VNM	Vietnam	SC-PP-oil	CO-HF-PP	630	kt	2009	IEA-SB
VNM	Vietnam	SC-PP-oil	CO-LF-PP	22	kt	2009	IEA-SB
VNM	Vietnam	SC-PP-oil	CO-PP	477	kt	2009	IEA-SB
YEM	Yemen	CEM	CEM	4000	kt	2009	USGS, 2012 (2009 data)
YEM	Yemen	OR	CO-OR	4068	kt	2009	IEA-SB
YEM	Yemen	SC-DR-oil	CO-LF-DR	1327	kt	2009	IEA-SB
YEM	Yemen	SC-IND-oil	CO-LF-IND	802	kt	2009	IEA-SB
YEM	Yemen	SC-PP-gas	NG-PP	4162	TJ	2009	IEA-SB
YEM	Yemen	SC-PP-oil	CO-HF-PP	1652	kt	2009	IEA-SB
YEM	Yemen	SC-PP-oil	CO-LF-PP	349	kt	2009	IEA-SB
YEM	Yemen	SC-PP-oil	CO-PP	586	kt	2009	IEA-SB
ZAF	South Africa	CEM	CEM	11500	kt	2009	USGS, 2012 (2009 data)
ZAF	South Africa	GP	GP-L	191833.7	kg	2010	National information: Leaner, 2012. (pers. comm.)
ZAF	South Africa	NFMP	AL-P	807	kt	2010	USGS, 2012 (2010 data)
ZAF	South Africa	NFMP	CU-P	89453	t	2009	USGS, 2012 (2009 data)
ZAF	South Africa	NFMP	PB-S	55000	t	2009	USGS, 2012 (2010 data)
ZAF	South Africa	NFMP	ZN-P	87000	t	2009	USGS, 2012 (2010 data)
ZAF	South Africa	OR	CO-OR	25040	kt	2009	IEA-SB
ZAF	South Africa	OR	NGL-OR	147	kt	2009	IEA-SB
ZAF	South Africa	PIP-C	COC-IND	330	kt	2009	IEA-SB
ZAF	South Africa	PISP	PIP	5266	kt	2010	Worldsteel Association, 2011
ZAF	South Africa	SC-DR-coal	HC-DR	11443	kt	2009	IEA-SB
ZAF	South Africa	SC-DR-oil	CO-HF-DR	586	kt	2009	IEA-SB
ZAF	South Africa	SC-DR-oil	CO-LF-DR	7417	kt	2009	IEA-SB
ZAF	South Africa	SC-IND-coal	HC-IND	9824	kt	2009	IEA-SB
ZAF	South Africa	SC-IND-oil	CO-HF-IND	10	kt	2009	IEA-SB
ZAF	South Africa	SC-IND-oil	CO-LF-IND	1041	kt	2009	IEA-SB
ZAF	South Africa	SC-PP-coal	HC-B-PP	173800	kt	2009	National information: Leaner, 2012. (pers. comm.)
ZAF	South Africa	SC-PP-oil	CO-LF-PP	12	kt	2009	IEA-SB
ZMB	Zambia	CEM	CEM	600	kt	2009	USGS, 2012 (2009 data)
ZMB	Zambia	GP	GP-L	1500	kg	2009	USGS, 2012 (2009 data)
ZMB	Zambia	NFMP	CU-P	334000	t	2009	USGS, 2012 (2009 data)
ZMB	Zambia	NFMP	PB-S	1000	t	2009	USGS, 2012 (2010 data)
ZMB	Zambia	OR	CO-OR	508	kt	2009	IEA-SB
ZMB	Zambia	SC-DR-oil	CO-HF-DR	17	kt	2009	IEA-SB
ZMB	Zambia	SC-DR-oil	CO-LF-DR	86	kt	2009	IEA-SB
ZMB	Zambia	SC-IND-coal	HC-IND	1	kt	2009	IEA-SB
ZMB	Zambia	SC-IND-oil	CO-HF-IND	51	kt	2009	IEA-SB
ZMB	Zambia	SC-IND-oil	CO-LF-IND	176	kt	2009	IEA-SB
ZMB	Zambia	SC-PP-coal	HC-B-PP	1	kt	2009	IEA-SB
ZMB	Zambia	SC-PP-oil	CO-LF-PP	9	kt	2009	IEA-SB
ZWE	Zimbabwe	CEM	CEM	300	kt	2009	USGS, 2012 (2009 data)
ZWE	Zimbabwe	GP	GP-L	4200	kg	2009	USGS, 2012 (2009 data)
ZWE	Zimbabwe	PIP-C	COC-IND	52	kt	2009	IEA-SB
ZWE	Zimbabwe	PISP	PIP	1	kt	2008	Worldsteel Association, 2011
ZWE	Zimbabwe	SC-DR-coal	HC-DR	323	kt	2009	IEA-SB
ZWE	Zimbabwe	SC-DR-oil	CO-LF-DR	323	kt	2009	IEA-SB
ZWE	Zimbabwe	SC-IND-coal	HC-IND	239	kt	2009	IEA-SB
ZWE	Zimbabwe	SC-IND-oil	CO-LF-IND	45	kt	2009	IEA-SB
ZWE	Zimbabwe	SC-PP-coal	HC-B-PP	1928	kt	2009	IEA-SB
ZWE	Zimbabwe	SC-PP-oil	CO-LF-PP	16	kt	2009	IEA-SB

¹ Sector and activity codes are defined in the Glossary; see pages 262–263.

Annex 6: Emission factors and technology profiles used in the calculation of emission estimates

General comments

During compilation of country-specific UEFs, an effort was made to use as much national data as possible.

In many of the literature sources, only abated country-specific EFs were reported, often with no specification on the abatement technologies and their implementation rates. Considering the methodology used in the current inventory, these AEFs were not directly applicable in the calculations. They were, however, used as benchmarks when calculating country-specific UEFs and generic UEFs. Where possible, information relating to abatement technologies was extracted and used in developing technology profiles.

The default technology profiles reflect assumptions based on available national information for countries in the respective groups (see Figure 2.5) regarding Hg reduction efficiencies associated with typically employed APCD configurations and their degree of application (including the application of integrated acid plants in the case of copper, lead and zinc smelters). In particular, use was made of available information from European countries, Republic of Korea, Japan and USA (Group 1); Australia and China (for coal burning in power plants) (Group 2); South Africa and China (Group 3); Russia (Group 4); India (Group 5).

These profiles represent a starting point for further refinement as additional (national) information becomes available.

This annex provides detailed information for the following sectors:

- Coal combustion, hard coal (anthracite and bituminous coal)
- Coal combustion, brown coal (sub-bituminous coal and lignite)
- Oil combustion
- Natural gas combustion
- Pig iron and steel production
- Non-ferrous metal production: copper (Cu)
- Non-ferrous metal production: lead (Pb)
- Non-ferrous metal production: zinc (Zn)
- Non-ferrous metal production: mercury (Hg) dedicated production from cinnabar ore
- Non-ferrous metal production: aluminium (Al) production from bauxite ore
- Cement production
- Oil refining
- Large-scale gold production
- Chlor-alkali industry

Coal combustion, hard coal (anthracite and bituminous coal)

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning combustion of hard coal (anthracite and bituminous coals).

Applied UEFs. These are shown in Table A6.1.

Comparative EFs. These are shown in Table A6.2.

Discussion of EFs. The generic default UEFs derived in this work are the result of expert evaluation and are intended to represent a reasonable general default factor, based on consideration of a wide range of literature, including the UNEP Toolkit (UNEP, 2011b), Paragraph-29 (UNEP, 2010a) study data, recent UNEP reports on coal combustion in power plants in China, Russia and India, peer-reviewed journal articles and other literature, including country-specific data and national reports.

Basic assumptions during calculations of UEF. For hard coal combustion, the UEFs represent the Hg content of coal; these are generally reported on a dry weight basis.

Applied technology profile. This is shown in Table A6.3.

Discussion of technology profile. In addition to discussions with representatives from different countries, the following references were important sources of information when deriving the technology profiles used in this work: UNEP (2010b: table 1 + table 4; 2011c,d), Pavlish et al. (2010), Pudasainee et al. (2009b, 2010), BREF (2006), Srivastava et al. (2006), Kim et al. (2010a,b), Nelson et al. (2009), UNEP/CIMFR-CSIR (2012), NESCAUM (2010).

Comparison with UNEP Toolkit factors. The intermediate UEF in the UNEP Toolkit (UNEP, 2011b) of 0.27 g/t is considerably higher than the default factor of 0.15 g/t applied in this work.

Comparison with 2005 inventory factors. The default factor applied when calculating emissions in 2005 (0.2 g Hg/t coal) is a global average abated factor. The default factors used in the current inventory are unabated and differentiated by coal type.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.1. Unabated emission factors (UEFs) applied for coal combustion, hard coal (anthracite and bituminous coal).

	Unabated emission factor			Source	Notes/adjustments to reported data
	low	intermediate	high units		
Generic default factors					
anthracite - PP	0.15		g/t		Expert evaluation of reasonable general default factor based on UNEP Toolkit (UNEP, 2011b), other literature, country-specific data.
bituminous - PP	0.15				
hard coal - IND	0.15				
hard coal - DR	0.15				
Australia					
PP anthracite	0.068		g/t		P. Nelson (pers. comm.)
PP bituminous	0.068		g/t		P. Nelson (pers. comm.)
IND hard coal	0.042		g/t		
DR hard coal	0.068		g/t		
Canada					
PP bituminous	0.070		g/t	Mazzi et al, 2006: figure 1	Average of data in figure 1
China					
PP bituminous	0.149		g/t	UNEP, 2011c: table 10	Average of data in table 10
IND hard coal	0.149		g/t		
DR hard coal	0.19		g/t	UNEP, 2011c; Sloss, 2008	
India					
PP bituminous	0.14		g/t	UNEP/CIMFR-CSIR, 2012	Average of coals burned in PPs in India
IND hard coal	0.292		g/t	Mukherjee et al., 2008	
DR hard coal	0.292		g/t		
Japan					
PP bituminous	0.0454		g/t		National information
IND hard coal	0.0454		g/t		National information
DR hard coal	0.0454		g/t		
Republic of Korea					
PP anthracite	0.082		g/t	Kim et al., 2010a: table 3	table 3
PP bituminous	0.046		g/t	Kim et al., 2010a,b	Mixed coals
IND hard coal	0.069		g/t	Kim et al., 2010a	Average of 0.082 and 0.046
DR hard coal	0.046		g/t	Kim et al., 2010b	Mixed coals
Russian Federation					
PP bituminous	0.063		g/t	UNEP, 2011d	Weighted average Hg content of coals consumed in Russia
IND hard coal	0.1		g/t		
DR hard coal	0.1		g/t		
South Africa					
PP bituminous	0.31		g/t	Masekoameng et al., 2010	Average
IND hard coal	0.31		g/t		
DR hard coal	0.31		g/t		
USA					
PP bituminous	0.1		g/t	Sloss, 2008	Srivastava et al., 2006

Table A6.2. Comparative emission factors (EFs) for coal combustion, hard coal (anthracite and bituminous coal).

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
All coals	0.050	0.270	0.500	g/t	UNEP, 2011b	UNEP Toolkit default input factor
Abated EF						
2005 inventory All coals – power plants		0.2			AMAP/UNEP, 2008	
2005 inventory All coals – residential and commercial boilers		0.3			AMAP/UNEP, 2008	

Table A6.3. Technology profile applied for coal combustion, hard coal (anthracite and bituminous coal).

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
PP anthracite									
Level 0: None		0							See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC		25		30	75	70	100	100	
Level 2: Particulate matter (FF)		50		5	20	30			
Level 3: Efficient APC: PM+SDA/wFGD		65		20					
Level 4: Very efficient APC: PM+FGD+SCR		70		40	5				
Level 5: Mercury specific		97		5					
PP bituminous									
Level 0: None		0							See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC	15	25	60	30	75	70	100	100	
Level 2: Particulate matter (FF)	40	50	93	5	20	30			
Level 3: Efficient APC: PM+SDA/wFGD	35	65	99	20					
Level 4: Very efficient APC: PM+FGD+SCR	90	90	99	40	5				
Level 5: Mercury specific	95	97	99	5					
IND hard coal									
Level 0: None		0				25	50	75	See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC		25		25	25	50	50	25	
Level 2: Particulate matter (FF)		50		25	50	25			
Level 3: Efficient APC: PM+SDA/wFGD		50		25	25				
Level 4: Very efficient APC: PM+FGD+SCR		90		25					
Level 5: Mercury specific		97							
DR hard coal									
Level 0: None		0		50	50	100	100	100	See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC		25		50	50				
COUNTRY-SPECIFIC PROFILES									
Republic of Korea									
PP anthracite									
SCR+cESP+wFGD		69		100					Pudasainee et al., 2009b
PP bituminous									
cESP+wFGD	35	47	58	50					Pudasainee et al., 2010
SCR+cESP+wFGD	44	61	71	50					

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
Australia									
PP bituminous									
ESP		46.5			75				Nelson et al., 2009: Table 44
FF		83.1			19				
ESP/FF		90			6				
South Africa									
PP coal not defined									
ESP		25				69			Masekoameng et al., 2010 (reduction efficiency, generic)
FF		50				20			
ESP+FF		50				11			
Brazil									
PP coal not defined									
ESP+PS		25				100			This work
Mexico									
PP coal not defined									
lowNOx						35.6			This work
modNOx						7.8			
ESP						5.2			
SCR						1.7			
India									
PP coal not defined									
ESP		10						100	UNEP/CIMFR-CSIR, 2012 (applied df 0.9)
Europe (EU25+Norway)									
PP bituminous									
FF		40		40					BREF, 2006
ESP/FF+FGD		75		30					
ESP/FF+FGD+high dust SCR		90		30					
Sweden									
PP bituminous									
Particulate matter (FF)		50		20					National comments
ESP/FF+FGD+high dust SCR		90		80					
Russian Federation									
PP bituminous									
Cyclone (CYC)		2					2.7		UNEP, 2011d
CYC+PS		5					6.2		
PS+ESP		10					14.9		
Cold side ESP		10					16.4		
CYC+ESP		10					6.4		
PS		10					53.4		
China and Hong Kong ^a									
PP all coals									
FF		50			7				National comments
ESP		26			7				
ESP+FGD		65			72				

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
SCR+ESP+FGD		69			14				
USA									
PP bituminous									
None/hESP		0		2.7					NESCAUM, 2010
cESP		25		20.8					
ACI		50		2.7					
FB+cESP		50		0.5					
ESP+wFGD		60		58.8					
dFGD+FF		70		2.7					
FB+FF		70		0.9					
FB+dFGD+FF		70		0.8					
FF		70		3.6					
FF+wFGD		80		6.5					

^a China – assigned to Group 2 for coal burning in power stations (in Group 3 for other sectors).

Coal combustion, brown coal (sub-bituminous coal and lignite)

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning combustion of brown coal (sub-bituminous coal and lignite).

Applied UEFs. These are shown in Table A6.4.

Comparative EFs. These are shown in Table A6.5.

Discussion of EFs. The generic default UEFs are derived in this work as expert evaluation of a reasonable level of a general default factor, based on a literature survey including UNEP Toolkit (UNEP, 2011b) and other literature, including country-specific data.

During compilation of country-specific UEFs, an effort was made to use as much national data as possible. One issue that arose during this work was that some lignite and sub-bituminous coals have very high moisture content (up to 50% in some coals burned in power plants in Australia; P. Nelson pers. comm.). If high moisture content coals are burned (without drying), then there is potential for over-estimating EFs if these are derived from coal Hg content values on a dry weight basis without adjusting for the moisture content.

Basic assumptions during calculations of UEF. For brown coal combustion, the UEFs represent the Hg content of coal as burned.

Applied technology profile. This is shown in Table A6.6.

Discussion of technology profile. In addition to discussions with representatives from different countries, the following references were important sources of information when deriving the technology profiles used in this work: UNEP

(2010b: table 1 + table 4, 2011c,d), Pavlish et al. (2010); Pudasainee et al. (2009b, 2010), BREF (2006), Srivastava et al. (2006), Kim et al. (2010a,b), Nelson et al. (2009), UNEP/CIMFR-CSIR (2012), NESCAUM (2010).

Comparison with UNEP Toolkit factors. The intermediate UEF in the UNEP toolkit (UNEP, 2011b) of 0.27 g/t is considerably higher than the default factors of 0.1–0.15 g/t applied in this work.

Comparison with 2005 inventory factors. The default factor applied when calculating emissions in 2005 (0.2 g Hg/t coal) is a global average abated factor. The default factors used in the current inventory are unabated and differentiated by coal type.

Gaps/needs to improve factors and profiles. (1) Information base for assumptions regarding technology profiles. (2) Moisture content of lignite and sub-bituminous coals burned in different countries and the implications of high moisture content for emission factors that are normally derived from coal Hg content expressed on a dry weight basis.

Table A6.4. Unabated emission factors (UEFs) applied for coal combustion, brown coal (sub-bituminous coal and lignite).

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factors						
sub-bituminous - PP	0.15		g/t		Expert evaluation of reasonable general default factor based on UNEP Toolkit (UNEP, 2011b), other literature, country-specific data.	
lignite - PP	0.10					
brown coal - IND	0.15					
brown coal - DR	0.15					
Australia						
PP lignite	0.032		g/t	P. Nelson (pers. comm.)	UEF takes into account high moisture content of coal	
PP sub-bituminous	0.032		g/t			
IND brown coal	0.068		g/t			
DR brown coal	0.032		g/t			
Canada						
PP sub-bituminous/lignite	0.07		g/t	Mazzi et al, 2006	Average of data in figure 1	
Germany						
PP lignite	0.063		g/t		UEF takes into account high moisture content of coal	
Russia						
PP lignite	0.063		g/t	UNEP, 2011d	Weighted average Hg content of coals consumed in Russia	
IND brown coal	0.1		g/t	UNEP, 2011d		
DR brown coal	0.1		g/t	UNEP, 2011d		
India						
PP lignite	0.140		g/t	UNEP.CIMFR-CSIR, 2012	Average of Indian coals burned in PPs	
IND brown coal	0.292		g/t	Mukherjee et al., 2008		
Mexico						
PP sub-bituminous	0.293		g/t	This work	Non-washed coal, Maiz, 2008	
IND brown coal	0.293		g/t			
USA						
PP sub-bituminous	0.055		g/t	UNEP, 2010a; This work (A. Kolker, pers. comm.)	UEF takes into account high moisture content of coal	

Table A6.5. Comparative emission factors (EFs) for coal combustion, brown coal (sub-bituminous coal and lignite).

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
All coals	0.050	0.270	0.500	g/t	UNEP, 2011b	UNEP Toolkit default input factor
Abated EF						
2005 inventory All coals – power plants		0.2			AMAP/UNEP, 2008	
2005 inventory All coals – residential and commercial boilers		0.3			AMAP/UNEP, 2008	

Table A6.6. Technology profile applied for coal combustion, brown coal (sub-bituminous coal and lignite).

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
PP sub-bituminous									
Level 0: None		0							See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC	0	10	25	30	75	70	100	100	
Level 2: Particulate matter (FF)	20	50	85	5	20	30			
Level 3: Efficient APC: PM+SDA/wFGD	0	40	75	20					
Level 4: Very efficient APC: PM+FGD+SCR	0	25	47	40	5				
Level 5: Mercury specific	50	75	95	5					
PP lignite									
Level 0: None		0							See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC	0	2	10	30	75	70	100	100	
Level 2: Particulate matter (FF)	0	5	10	5	20	30			
Level 3: Efficient APC: PM+SDA/wFGD	0	20	55	20					
Level 4: Very efficient APC: PM+FGD+SCR	0	20	96	40	5				
Level 5: Mercury specific	50	75	95	5					
IND brown coal									
Level 0: None		0				25	50	75	See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC		5		25	25	50	50	25	
Level 2: Particulate matter (FF)		50		25	50	25			
Level 3: Efficient APC: PM+SDA/wFGD		30		25	25				
Level 4: Very efficient APC: PM+FGD+SCR		20		25					
Level 5: Mercury specific		75							
DR hard coal									
Level 0: None		0		50	50	100	100	100	See discussion
Level 1: Particulate matter simple APC: ESP/PS/CYC		5		50	50				
COUNTRY-SPECIFIC PROFILES									
Australia									
PP sub-bituminous									
ESP		46.5		100					Nelson et al., 2009: table 43
Russian Federation									
PP sub-bituminous									
Cyclone (CYC)		2					11.8		UNEP, 2011d
CYC+PS		5					1.2		
PS+ESP		10					14.5		
Cold side ESP		10					37.7		
CYC+ESP		10					6.6		
PS		10					28.1		
USA									
PP sub-bituminous									
None/hESP		0		4.6					NESCAUM, 2010
cESP		10		35.9					

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
wFGD		25		16.5					NESCAUM, 2010
FF		30		8.3					
FF+wFGD		40		4					
dFGD+FF		50		5					
ACI		80		25.7					
PP lignite									
FB+FF		20		65.4					
ACI		50		32.9					
FB+ACI		80		1.7					

Oil combustion

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning combustion of crude oil, heavy fuel oil and light fuel oil.

Applied UEFs. These are shown in Table A6.7.

Comparative EFs. These are shown in Table A6.8.

Discussion of EFs. Default UEFs used in this work were based on the lower range default input factors employed in the UNEP Toolkit (UNEP, 2011b), using twice these values. This choice was based on comparison of the UNEP Toolkit defaults and available information on Hg content of crude and refined oil.

Applied technology profile. This is shown in Table A6.9.

Discussion of technology profile. It was assumed that only major point sources in Group 1–3 countries will employ APCDs that reduce Hg emissions from oil combustion,

and the reported effectiveness of such devices for reducing Hg emissions from oil combustion is generally low. For sources other than power plants and industrial facilities it was assumed that no emission abatement is applied.

Comparison with UNEP Toolkit factors. The UNEP Toolkit default input factors of 0.055 g/t for crude and heavy fuel oil and 0.006 g/t for light fuel oil are somewhat higher than the values selected for use in this work, which were based on the lower range UNEP default factors.

Comparison with 2005 inventory factors. An abated EF of 0.001 g/t was applied in the 2005 inventory calculations, comparable to that for light fuel oil burning in the 2010 inventory, but relatively low compared with the UEFs applied to crude oil and heavy fuel oil combustion in 2010.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.7. Unabated emission factors (EFs) applied for oil combustion.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factors						
crude oil - PP		0.01				
heavy fuel oil - PP		0.02				
light fuel oil - PP		0.002				
crude oil - IND		0.01				
heavy fuel oil - IND		0.02		g/t	UNEP, 2011b	Twice the UNEP Toolkit default minimum value, see discussion.
light fuel oil - IND		0.002				
crude oil - DR		0.01				
heavy fuel oil -DR		0.02				
light fuel oil - DR		0.002				
Republic of Korea						
PP crude oil		0.027		g/t	Kim et al., 2010a	

Table A6.8. Comparative emission factors (EFs) for oil combustion.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
Crude oil	0.005	0.055	0.300	g/t	UNEP, 2011b	
Heavy fuel oil	0.010	0.055	0.100		UNEP, 2011b	
Light fuel oil	0.001	0.006	0.010		UNEP, 2011b	
Abated EF						
2005 inventory		0.001			AMAP/UNEP, 2008	

Table A6.9. Technology profile applied for oil combustion.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
PP crude oil									
None		0				50	100	100	
PM+FGD (cESP, scrubbers+FGD)		50		100	100	50			
PP heavy fuel oil									
None		0				50	100	100	
PM+FGD (cESP, scrubbers+FGD)		50		100	100	50			
PP light fuel oil									
None		0		50	50	100	100	100	
PM+FGD (cESP, scrubbers+FGD)		50		50	50				
IND crude oil									
None		0		50	50	50	100	100	
PM (cESP, scrubbers)		10		50	50	50			
IND heavy fuel oil									
None		0		50	50	50	100	100	
PM (cESP, scrubbers)		10		50	50	50			
IND light fuel oil									
None		0		50	50	100	100	100	
PM (cESP, scrubbers)		10		50	50				
DR crude oil									
None		0		100	100	100	100	100	
DR heavy fuel oil									
None		0		100	100	100	100	100	
DR light fuel oil									
None		0		100	100	100	100	100	

Natural gas combustion

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning combustion of natural gas (activity data in TJ, gross calorific value).

Applied UEFs. These are shown in Table A6.10.

Comparative EFs. These are shown in Table A6.11.

Discussion of EFs. Calorific values of natural gas vary (e.g., North Sea natural gas 39 MJ per m³ (NPL, 2012); generic value 43 MJ per m³ (Engineering Toolbox, 2012)); a value of 40 MJ per m³ has been assumed for purposes of developing a UEF in this work. The UNEP Toolkit emission factors (0.2 and 100 µg/m³, for pipeline and raw/untreated gas respectively) used as a basis for suggested generic UEF values are derived from analysis of Hg concentrations in natural gas. Emissions estimates assume combustion of pipeline/consumer gas (with low Hg content); if raw/untreated gas is burned at installations the emissions would be considerably higher (by a factor of about 500).

Applied technology profile. This is shown in Table A6.12.

Discussion of technology profile. It was assumed that APCDs are either absent at sites where natural gas is burned, or are inefficient at reducing Hg emissions to air from this source.

Comparison with UNEP Toolkit factors. The UNEP Toolkit (UNEP, 2011b) input factors are used as the basis for the UEFs. The Toolkit document indicates use of a conversion factor of 26 Nm³/TJ for converting between natural gas volume and calorific value; the correct factor based on the current work would be 25 000 Nm³/TJ.

Comparison with 2005 inventory factors. Emissions from natural gas combustion were not included in the 2005 inventory.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles and type of gas burned.

Table A6.10. Unabated emission factors (UEFs) applied for natural gas combustion.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor		0.005			UNEP, 2011b	Pipeline/consumer quality gas; UEF g/TJ based on UNEP (2011b) value of 0.2 µg/m ³

Table A6.11. Comparative emission factors (EFs) for natural gas combustion.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
		2.5		g/TJ	UNEP, 2011b	Raw/pre-cleaned gas; UEF g/TJ based on UNEP (2011b) value of 100 µg/m ³
		0.2		µg/m ³		Pipeline/consumer quality gas; DF = 1
		100				Raw/pre-cleaned gas; DF = 1

Table A6.12. Technology profile applied for natural gas combustion.

Technology	Reduction efficiency, %			Degree of application, %					Source
	low	Intermediate	high	Country group					
				1	2	3	4	5	
Default profile									
None	0			100	100	100	100	100	

Pig iron and steel production

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary production of pig iron. Note: Emission estimates associated with secondary steel production are not included in the calculation methodology.

Applied UEFs. These are shown in Table A6.13.

Comparative EFs. These are shown in Table A6.14.

Discussion of EFs. During compilation of country-specific UEFs, an effort was made to use as much national data as possible. Most countries do not have complete mass balances but national data on material consumption and/or Hg content was used instead of generic values wherever possible. The 2010 inventory applied a UNEP Toolkit-based default UEF of 0.05 g/t pig iron; however, the higher BREF-based UEF (0.87 g/t pig iron) is a reasonable alternative for a UEF with fuels included.

The following literature sources were studied: UNEP (2011b), BREF (2012a), National information (provided by Mexico, Brazil, China and South Africa); Fukuda et al. (2011), Nelson (2007), Nelson et al. (2009), Kim et al. (2010a), Streets et al. (2009, 2011), COWI.

Basic assumptions during calculations of UEF.

- Production processes included are coke oven, pellet plant, sinter plant, blast furnace and basic oxygen steelmaking. The latter makes an insignificant input into the total Hg emissions
- All coke added in sinter plant, pellet plant, blast furnace and basic oxygen steelmaking is produced in coke ovens – parts of the integrated primary steel-making facilities
- Import/export of sinter, pellets and fuels is not considered
- Hg content of product (pig iron) is zero, almost all Hg is volatilised during thermal processes, especially sintering and pelletising
- Recycling of filter materials on-site is not considered for UEF since recycling is only possible if abatement is present
- Energy re-use (further combustion of off-gases) is not considered.

Fuel and raw material consumption per 1 t of pig iron, according to the BREF-based mass balance:

- Iron ore: 0.09–2.96 t, intermediate value – 1.42 t (BREF, 2012a)
- Limestone: 0.02–0.30 t, intermediate value – 0.17 t (BREF, 2012a)
- Coal: 0.35–1.06 t, intermediate value – 0.68 t (BREF, 2012a)
- Oil: 0.00–0.12 t, intermediate value – 0.03 t (BREF, 2012a).

Range of Hg content of materials used for UEF based on BREF mass balance:

- Iron ore: 0.0006–0.06 g/t, intermediate value – 0.03 g/t

(UNEP, 2011b; Fukuda et al., 2011)

- Limestone: 0.02–0.05 g/t, intermediate value – 0.03 g/t (UNEP, 2011b; Fukuda et al., 2011)
- Coal: 0.05–0.06 g/t, intermediate value – 0.055 g/t (Fukuda et al., 2011; Nelson, 2007)
- Oil: 0.026 g/t (Fukuda et al., 2011).

The following *ratios* (t/t) are used:

- Coal / coke = 1.22–1.35 (BREF, 2012a)
- Hot metal / liquid steel = 0.79–0.93 (BREF, 2012a)

For all UEFs, *distribution factor* = 1. Other pathways (sector-specific treatment/disposal) are assumed to refer to treatment of residues from abatement equipment (UNEP, 2011b).

Applied technology profile. This is shown in Table A6.15.

Discussion of technology profile. Steel-making facilities are usually complex systems including several processes at different sites, all of which are usually equipped with separate APCDs. In the technology profiles in Table A6.15 APCDs installed at sinter plants are mainly considered because, according to the available information (UNEP, 2011b, country inventories, reports, etc.), their input into Hg emissions is the most significant.

The following literature sources were studied: UNEP (2011b), BREF (2012a), Fukuda et al. (2011), Nelson et al. (2009), and national information (provided by Brazil, China, Republic of Korea and Mexico).

Comparison with UNEP Toolkit factors. The default UEF used (0.05 g Hg/t pig iron production) is the same as the UNEP Toolkit default factor.

Potential for double counting. Generic EFs for primary pig iron production compiled by the Swedish Environmental Institute (IVL) based on BREF mass-balance include use of fuels: oil, coke (produced from coal) and coal (added as pulverised coal and used for coke production). Coal and oil combustion in power plants and industry, accounted in other sections of this inventory, exclude coal consumption in coke production so there should be no double counting.

Country-specific emission factors are derived using the same principle.

Comparison with 2005 inventory factors. The default **unabated** emission factor used in the current inventory (0.05 g Hg/t pig iron production) is 25% higher than the default **abated** emission factor applied when calculating emissions in 2005 (0.04 g Hg/t steel production). The latter is a global average abated factor whereas the former is an unabated factor. It should also be noted that the 2005 emission factor was applied to steel rather than pig-iron production.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles and emission factors for secondary steel production.

Table A6.13. Unabated emission factors (UEFs) applied for pig iron and steel production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	0.01	0.05	0.50			Expert evaluation based on UNEP (2011b), BREF (2012a) and country-specific data. Fuels (coal, coke, oil) are included
Australia	0.021	0.084	0.162		BREF, 2012a; Fukuda et al., 2011; Nelson, 2007	National data: 0.03 g Hg/t iron ore; 0.05 g Hg/t coal
Brazil	0.021	0.088	0.173		BREF, 2012a; Fukuda et al., 2011; National information	National data: 0.03 g Hg/t iron ore
Chile	0.050	0.525	1.000		COWI	National data: total Hg input 0.05–1 g Hg/t pig iron
Japan	0.108	0.118	0.128	g/t (primary) pig-iron production	BREF, 2012a; Fukuda et al., 2011	Reported input per t of liquid steel (0.101 g/t) is re-calculated for pig iron using BREF ratio (≈ 0.86 t of pig iron per 1 t of liquid steel)
Republic of Korea	0.028	0.029	0.030		Kim et al., 2010a	UEFs reported in Kim et al., 2010a
Mexico	0.026	0.078	0.226		BREF, 2012a; National information	National data: 0.51 t coal/t pig iron.
Russia	0.024	0.132	0.260		BREF, 2012a; UNEP, 2011b	National data: 0.06 g Hg/t iron ore; 0.05 g Hg/t limestone.
South Africa	0.007	0.059	0.208		BREF, 2012a; Masekoameng et al., 2010	National data: 0.14–0.2 t of coal per 1 t of pig iron
USA	0.018	0.067	0.177		BREF, 2012a; UNEP, 2011b	National data: 0.0006–0.032 g Hg/t iron ore

Table A6.14. Comparative emission factors (EFs) for pig iron and steel production.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air		0.05		g/t (primary) pig-iron production	UNEP, 2011b	Default input factor 0.05 g/t; DF =1 if no abatement assumed. Fuels are excluded
UEF based on BREF mass balance	0.018	0.087	0.260	g/t (primary) pig-iron production	BREF, 2012a; UNEP, 2011b; Fukuda et al., 2011; Nelson, 2007	Mass balances for the considered production processes; fuels (coal, oil) are included
	0.0004	0.049	0.193			Fuels excluded
EMEP/EEA	0.02	0.1	0.36	g/t (primary) steel production	EMEP/EEA, 2009	Numbers in g/t steel adjusted with the ratio 0.788–0.931 t pig iron/t steel (BREF)
	0.021	0.116	0.46	g/t (primary) pig-iron production		
	0.016	0.049	0.15	g/t sinter		Numbers in g/t sinter adjusted with the ratio 0.116–1.621 t sinter/t pig iron (BREF)
	0.002	0.053	0.24	g/t (primary) pig-iron production		
Abated EF						
UNEP Toolkit abated input to air		0.048		g/t (primary) pig-iron production	UNEP, 2011b	Default input factor 0.05 g/t; DF =0.95 assuming abatement (wet scrubber or similar)
2005 inventory		0.04		g/t (primary) steel production	AMAP/UNEP, 2008	AEF was applied to steel production as opposed to pig-iron production activity data
BREF-based	0.0001	0.104	0.207	g/t sinter	BREF, 2012a	European sinter plants. Numbers in BREF are presented as intervals. Intermediate value here is an arithmetic average
	0.00001	0.168	0.336	g/t (primary) pig-iron production		Numbers in g/t sinter adjusted with the ratio 0.116–1.621 t sinter/t pig iron (BREF)

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
EMEP/EEA	0.012	0.018	0.036	g/ t sinter	EMEP/EEA, 2009	Wet gas desulphurisation
	0.006	0.009	0.018			Dry ESP
	0.004	0.006	0.012			ACI + FF
	0.001	0.020	0.058	g/t (primary pig-iron production)		Numbers in g/t sinter adjusted with the ratio 0.116–1.621 t sinter/t pig iron (BREF). Same abatement implied.
	0.0007	0.010	0.029			
	0.0005	0.007	0.019			

Table A6.15. Technology profile applied for pig iron and steel production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
Level 0: None		0					20	100	BREF, 2012a; UNEP, 2011b; Fukuda et al., 2011
Level 1: Basic APC: WS(+FF) (sinter plant)		5			20	50	80		
Level 2: Standard APC: ESP/CYC/FGD (sinter plant)		20		30	80	50			
Level 3: Efficient APC: ESP+FGD/ACT/ESP+ACT (sinter plant)	40	55	75	60					
Level 4: Very efficient APC: ESP+ACT/RAC (sinter plant)	95	97	99	10					
COUNTRY-SPECIFIC PROFILES									
Australia									
Sinter plant: Regenerative activated carbon process + Pelletising plant: AIRFINE = ESP/CYC + quench. scrubber + fine WS	95	97	99		100				BREF, 2012a; Nelson et al., 2009
Brazil									
Level 1		5				33			National information
Level 2		20				67			
China									
WS		5				5			National information
ESP + FF		20				85			
ESP + FGD		55				10			
Republic of Korea									
ESP+SCR+FGD		50		100					National information
Japan									
Sinter plant ESP + Blast furnace FF/ESP		26		30					Fukuda et al., 2011
Sinter plant ESP+FGD + Blast furnace FF/ESP		47		30					
Sinter plant ESP+ACT + Blast furnace FF/ESP		75		40					
Mexico									
Direct Flame Afterburner with Heat Exchanger / ESP / Wet cyclonic separator/ Gravity collector		20				1			National information
Venture scrubber		20				30			
Cyclones		20				10			
FF		5				30			
Mat or panel filter		20				10			
None		0				19			
Sweden									
Dust abatement+off gas treatment		50		100					National information (two plants)

Non-ferrous metal production: copper (Cu)

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary copper production (and in some cases total copper production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.16.

Comparative EFs. These are shown in Table A6.17.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2010a,b), BREF (2009), EMEP/EEA (2009), Hylander and Herbert (2008), Kim et al. (2010a), Kumari (2011), Nelson et al. (2009), OUTOTEC, Streets et al. (2009, 2011), national information (provided by Brazil, Mexico and Republic of Korea); Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF.

- Initial oxidation stage (roasting or sintering of concentrate) is considered to be major source of Hg emissions
- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes
- Fuels can be a source of minor Hg inputs (UNEP, 2011b) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in the UNEP Toolkit (UNEP, 2011b) is therefore the same as Hg content of Cu concentrate.
- An integrated acid plant is considered as a part of applied technology profile, see discussion of technology profile.

The range of concentrate/copper ratios was estimated based on the following data:

- Copper content of concentrates: 15–51%, intermediate value 30% (UNEP, 2011b; BREF, 2009; EMEP/EEA, 2009);
- Rate of copper recovery from concentrates: 93% (UNEP, 2011b);
- Given concentrate/copper ratios: 2.84 (BREF, 2009), 3.33 (OUTOTEC).

For all UEFs, distribution factor = 1. Other pathways are assumed to refer to treatment of residues from abatement equipment (UNEP 2011b; Maag, pers. comm.).

Applied technology profile. This is shown in Table A6.18.

Discussion of technology profile. Particular attention should be given to the comments in table note 'b'. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an

acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 95% plus 90% of the remaining 5% = effective 99.5% reduction.

The following literature sources were studied: UNEP (2010a, 2011b), BREF (2009), Hylander and Herbert (2008), Kim et al. (2010a), OUTOTEC, national information (provided by Brazil, Mexico and Republic of Korea); Maag, pers. comm.; Wang, pers. comm.

Comparison with UNEP Toolkit factors. The default factors used (26.9 and 107 g/t Cu produced, for assumed lower and higher Hg-content ores, respectively) are (rounded) equivalent to the default factors under discussion for proposed revisions to the UNEP Toolkit (with adjustment for the application to metal production activity data rather than concentrate). These are higher than the default input factors for Cu production employed in the current UNEP Toolkit (UNEP, 2011b).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in ores, metal concentrates and reject materials. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2005 inventory factors. The default **abated** EF applied in calculations for 2005 (5 g Hg/t Cu produced) is considerably lower than the default **unabated** EF used in the current inventory (107 g/t Cu produced). It is worth noting, however, that the factor 5 g Hg/t assumes a high degree of abatement (effectively, the application of integrated acid plants to all production).

Acid plants decrease Hg emissions significantly, and they are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 107 g/t would correspond to an abated EF of around 2–11 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.16. Unabated emission factors (UEFs) applied for non-ferrous metal production: copper.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	2	107	717	g/t Cu produced (primary production)	UNEP, 2011b; OUTOTEC; BREF, 2009; country-specific data	Expert evaluation including UNEP Toolkit updating; intermediate based on 30 g/t in concentrate (low/high based on 1 and 100 g/t in concentrate, respectively)
Canada	4.8	8.2	16.5			Based on national data on Hg content of concentrate: 2.3 g/t

Table A6.17. Comparative emission factors (EFs) for non-ferrous metal production: copper.

	Emission Factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	1	8	15	g/t concentrate used	UNEP, 2011b	Default input factor (Hg content of concentrate) 1–15 g/t; DF=1.
	2.1	28.7	107.5	g/t Cu produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Cu ratio 2.11–7.17 (intermediate value 3.58)
Proposed revision to UNEP Toolkit	1	30	100	g/t concentrate used		Proposed input factor for high Hg content concentrates; DF=1.
		7.5				Proposed input factor for low Hg content concentrates (from asymmetric distribution plot)
	2.1	107.5	716.8	g/t Cu produced		Adjusted using concentrate/Cu ratio 2.11–7.17 (intermediate value 3.58)
		26.9				Adjusted from 7.5 g/t in concentrate (from asymmetric distribution plot)
Abated EF						
2005 inventory		5		g/t Cu produced	AMAP/UNEP, 2008	
EMEP/EEA	0.021	0.031	0.052	g/t Cu produced	EMEP/EEA, 2009	Abatement not specified (default)
UNEP Toolkit abated input to air	0.1	0.8	1.5	g/t concentrate used	UNEP, 2011b	Default input factor 1–15 g/t. Dedicated Hg removal techniques. DF = 0.1
	0.2	2.9	10.8	g/t Cu produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Cu ratio 2.11–7.17 (intermediate value 3.58)
Proposed revision to UNEP Toolkit	0.9	27.0	90.0	g/t concentrate used		Default input factor 1–100 g/t. Coarse, dry PM retention. DF = 0.9
	0.5	14.7	49.0			Default input factor 1–100 g/t. Wet gas cleaning. DF = 0.49
	0.1	3.0	10.0			Default input factor 1–100 g/t. Wet gas cleaning + acid plant. DF = 0.1
	0.02	0.6	2.0			Default input factor 1–100 g/t. Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02
	1.9	96.8	645.2	g/t Cu produced		UNEP TKR numbers adjusted using concentrate/Cu ratio 2.11–7.17. Coarse, dry PM retention. DF = 0.9
	1.0	52.7	351.3			UNEP TKR numbers adjusted Wet gas cleaning. DF = 0.49
	0.2	10.8	71.7			Wet gas cleaning + acid plant. DF = 0.1
	0.04	2.2	14.3			Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02

Table A6.18. Technology profile applied for non-ferrous metal production: copper.

Technology	Reduction efficiency, %			Degree of application, %					Source
	low	Intermediate	high	Country group					
				1	2	3	4	5	
DEFAULT PROFILES									
Level 0: None or simple particle filters		0				2.5	5	10	UNEP, 2010a, 2011b; BREF, 2009; Hylander and Herbert , 2008; Kim et al., 2010a; Li et al., 2010
Level 1: Simple APC: particle control only		10							
Level 2: Basic APC: particle control + WGC ^a		50				2.5	5		
Level 3: Efficient APC: particle control + WGC + AP ^b		95		20	100	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX ^c + AP		99		80					
COUNTRY-SPECIFIC PROFILES									
China									
None (artisanal production)		0				3.36			National comments
APC but no acid production		50				0.7			
APC with acid production		95				95.94			
Republic of Korea									
ESP/Sulphuric acid process/Gas scrubber		99.9		100					Kim et al., 2010a

^a Particle control = cyclones and ESP, WGC = Wet gas cleaning; ^b integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; ^c Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 90%.

Non-ferrous metal production: lead (Pb)

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary Pb production (and in some cases total production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.19.

Comparative EFs. These are shown in Table A6.20.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2010a, 2011b), BREF (2009), EMEP/EEA (2009), Hylander and Herbert (2008), Kim et al. (2010a), Kumari (2011), Nelson et al. (2009), OUTOTEC, Streets et al. (2009, 2011), national information (provided by Brazil, Mexico and Republic of Korea); Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF:

- Initial oxidation stage (roasting or sintering of concentrate)

is considered to be major source of Hg emissions

- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes
- Fuels can be a source of minor Hg inputs (UNEP TK) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in UNEP TK is therefore the same as Hg content of Pb concentrate
- An integrated acid plant is considered as a part of applied technology profile, see below.

The range of **concentrate/lead ratios** was estimated based on the following data:

- Lead content of concentrates: 35–90%, intermediate value 50% (UNEP, 2011b; BREF, 2009)
- Rate of lead recovery from concentrates: 80% (Paragraph 29 study [UNEP, 2010a] response from Brazil);
- Given concentrate/lead ratios: 2.50 (COWI), 3.33 (OUTOTEC).

For all UEFs, distribution factor = 1. Other pathways are

assumed to refer to treatment of residues from abatement equipment (UNEP, 2011b; Maag, pers. comm.).

Applied technology profile. This is shown in Table A6.21.

Discussion of technology profile. Particular attention should be given to the comments in table note 'b'. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 95% plus 90% of the remaining 5% = effective 99.5% reduction.

The following literature sources were studied: UNEP (2010a, 2011b), BREF (2009), Hylander and Herbert (2008), Kim et al. (2010a); OUTOTEC, national information (provided by Brazil, Mexico and Republic of Korea); Maag, pers. comm.; Wang, pers. comm.

Comparison with UNEP Toolkit factors. The default factors used (12.5 and 75 g/t Pb produced, for assumed lower and higher Hg content ores, respectively) are (rounded) equivalent to the default factors under discussion for proposed revisions to the UNEP Toolkit (with adjustment for the application to metal production activity data rather than concentrate). These are lower than the default input factors for Pb production employed in the current UNEP Toolkit (UNEP, 2011b).

Potential for double counting. UNEP TK EFs are derived based on analysis of Hg concentrations in ores, metal concentrates and reject materials. Country-specific EFs are

derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2005 inventory factors. The default **abated** EF applied in calculations for 2005 (3 g Hg/t Pb produced) is considerably lower than the default **unabated** EF used in the current inventory (75 g/t Pb produced). It is worth noting, however, that the factor 3 g Hg/t Pb produced implies a high degree of abatement (effectively, the application of integrated acid plants to all production).

Acid plants decrease Hg emissions significantly, and they are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 75 g/t would correspond to an abated EF of around 1–8 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.19. Unabated emission factors (UEFs) applied for non-ferrous metal production: lead.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	3	75	214			Expert evaluation including UNEP Toolkit updating; intermediate based on 30 g/t in concentrate (low/high based on 2 and 60 g/t in concentrate, respectively)
Bulgaria, Kazakhstan, Dem. Rep. Korea, Romania, Morocco, India, Myanmar, Russia, Serbia and Montenegro		18.7		g/t Pb produced (primary production)	UNEP, 2010a, 2011b; BREF, 2009; country-specific data	Based on 7.5 g/t in concentrate
Argentina, Bolivia, China, Iran, Mexico, Peru		15.6				Based on 6.2 g/t in concentrate
Australia, Belgium, Italy, France, Germany, Japan, Republic of Korea, Poland, Sweden, United Kingdom, United States		12.5				Based on 5 g/t in concentrate
Canada	3.8	6.8	9.6			Based on national data on Hg content of concentrate: 2.7 g/t

Table A6.20. Comparative emission factors (EFs) for non-ferrous metal production: lead.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	2	101	200	g/t concentrate used	UNEP, 2011b	Default input factor (Hg content of concentrate) 2–200 g/t; DF to air =1.
	2.8	252.5	714.3	g/t Pb produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Pb ratio 1.39–3.57 (intermediate value 2.50)
Proposed revision to UNEP Toolkit	2	30	60	g/t concentrate used		Proposed input factor for high Hg content concentrates; DF to air =1.
		12.5				Proposed input factor for low Hg content concentrates (from asymmetric distribution plot)
	2.8	75.0	214.3	g/t Pb produced		Adjusted using concentrate/Pb ratio 1.39–3.57 (intermediate value 2.50)
		31.3				Adjusted from 12.5 g/t in concentrate (from asymmetric distribution plot)
Abated EF						
2005 inventory		3		g/t Pb produced	AMAP/UNEP, 2008	
EMEP/EEA	0.33	1	3	g/t Pb produced	EMEP/EEA, 2009	BAT production technologies (AP)
	0.32	0.95	2.9			Dry ESP (+AP)
	0.3	0.9	2.7			FF (+AP)
	0.0333	0.1	0.3			ACI + FF + FGD (+AP)
UNEP Toolkit abated input to air (current)	0.2	10.1	20.0	g/t concentrate used	UNEP, 2011b	Default input factor 2–200 g/t. Dedicated Hg removal techniques. DF = 0.1
	0.3	25.3	71.4	g/t Pb produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Pb ratio 1.39–3.57 (intermediate value 2.50)
UNEP Toolkit abated input to air (on revision)	1.8	27.0	54.0	g/t concentrate used		Default input factor 2–60 g/t. Coarse, dry PM retention. DF = 0.9
	1.0	14.7	29.4			Default input factor 2–60 g/t. Wet gas cleaning. DF = 0.49
	0.2	3.0	6.0			Default input factor 2–60 g/t. Wet gas cleaning + acid plant. DF = 0.1
	0.04	0.6	1.2			Default input factor 2–60 g/t. Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02
	2.5	67.5	192.9	g/t Pb produced		UNEP TKR numbers adjusted using concentrate/Pb ratio 1.39–3.57. Coarse, dry PM retention. DF = 0.9
	1.4	36.8	105.0			Wet gas cleaning. DF = 0.49
	0.3	7.5	21.4			Wet gas cleaning + acid plant. DF = 0.1
	0.1	1.5	4.3			Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02

Table A6.21. Technology profile applied for non-ferrous metal production: lead.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None or simple particle filters	0					2.5	5	10	UNEP, 2010a, 2011b; BREF, 2009; Hylander and Herbert, 2008; Kim et al., 2010a; Li et al., 2010
Level 1: Simple APC: particle control only	10								
Level 2: Basic APC: particle control + WGC ^a	50					2.5	5		
Level 3: Efficient APC: particle control + WGC + AP ^b	95			20	100	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX ^c + AP	99			80					
COUNTRY-SPECIFIC PROFILE									
China									
None (artisanal production)	0					3.36			National comments
APC but no acid production	50					0.7			
APC with acid production	95					95.94			
Republic of Korea									
ESP/Sulphuric acid process/Gas scrubber	99			100					Kim et al., 2010a

^a Particle control = cyclones and ESP, WGC = Wet gas cleaning; ^b integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; ^c Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 90%.

Non-ferrous metal production: zinc (Zn)

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary Zn production (and in some cases total production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.22.

Comparative EFs. These are shown in Table A6.23.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2010a, 2011b); BREF (2009), EMEP/EEA (2009), Hylander and Herbert (2008), Kim et al. (2010a), Kumari (2011), Nelson et al. (2009), OUTOTEC, Streets et al. (2009, 2011), national information (provided by Brazil, Mexico and Republic of Korea); Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF:

- Initial oxidation stage (roasting or sintering of concentrate) is considered to be major source of Hg emissions
- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes
- Fuels can be a source of minor Hg inputs (UNEP TK) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in UNEP TK is therefore the same as Hg content of Zn concentrate
- An integrated acid plant is considered as a part of applied technology profile, see below.

The range of concentrate/zinc ratios was estimated based on the following data:

- Zinc content of concentrates: 40–60%, intermediate value 55% (Paragraph 29 study [UNEP, 2010a] from Brazil; BREF, 2009; Li et al., 2010)
- Rate of Zn recovery from concentrates: 95–97% (Li et al., 2010)
- Given concentrate/Zn ratios: 2.15 (Wang et al., 2010), 2.00 (OUTOTEC).

For all UEFs, distribution factor = 1. Other pathways are assumed to refer to treatment of residues from abatement equipment (UNEP 2011b).

Applied technology profile. This is shown in Table A6.24.

Discussion of technology profile. Particular attention should be given to the comments in table note 'b'. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 95% plus 90% of the remaining 5% = effective 99.5% reduction.

The following literature sources were studied: UNEP (2010a, 2011b), BREF (2009), Hylander and Herbert (2008), Kim et al. (2010a), OUTOTEC, national information (provided by Brazil, Mexico and Republic of Korea); Maag, pers. comm.; Wang, pers. comm.

Comparison with UNEP Toolkit factors. The default factors used (16 and 123 g/t Zn produced, for assumed lower and higher Hg content ores, respectively) are (rounded) equivalent to the default factors under discussion for proposed revisions to the UNEP Toolkit (with adjustment for the application to metal production activity data rather than concentrate). These are lower than the default input factors for Zn production employed in the current UNEP Toolkit (UNEP, 2011b).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in ores, metal

concentrates and reject materials. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2005 inventory factors. The default EF applied in calculations for 2005 (7 g Hg/t Zn produced) is considerably lower than the default EF used in the current inventory (123 g/t Zn produced. It is worth noting, however, that the factor 7 g Hg/t Zn produced implies a high degree of abatement (effectively, the application of integrated acid plants to all production).

Acid plants decrease Hg emissions significantly, and are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 123 g/t would correspond to an abated EF or around 1–7 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.22. Unabated emission factors (UEFs) for non-ferrous metal production: zinc.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factors	9	123	342		UNEP, 2011b; OUTOTEC; BREF, 2009	Expert evaluation including UNEP Toolkit updating; intermediate based on 65 g/t in concentrate (low/high based on 5 and 130 g/t in concentrate, respectively)
Brazil	12.6	165.4	333.8		UNEP 2010a; BREF, 2009	National data on Zn content of concentrate: 41%.
Canada	19.0	25.6	323.7			National data on Hg content of concentrate: 11–123 g/t
China	56.1	89.2	124.5		UNEP 2011b; Li et al., 2010; Wang et al., 2010	National data: Hg content of concentrate: 26.1–57.9 g/t (Li et al., 2010), concentrate/Zn ratio = 2.15 (Wang et al., 2010)
Russia	8.6	144.2	323.7	g/t Zn produced (primary production)	UNEP 2010a; BREF, 2009	National data on Hg content of concentrate: <5–123g/t
Australia	82.7	118.2	82.7			National data on Hg content of concentrate: 48–89 g/t
Spain	74.1	150.8	342.1			National data on Hg content of concentrate: 43 – >130 g/t
USA	8.6	31.5	55.3			National data on Hg content of concentrate: <5–21 g/t
Germany	10.3	277.7	431.6			National data on Hg content of concentrate: 6–164 g/t
Norway	103.4	113.8	157.9			National data on Hg content of concentrate: 60 g/t
Peru	8.6	69.4	386.8			National data on Hg content of concentrate: <5–147g/t

Table A6.23. Comparative emission factors (EFs) for non-ferrous metal production: zinc.

	Emission Factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	10	105	200	g/t concentrate used	UNEP, 2011b	Default input factor (Hg content of concentrate) 10–200 g/t; DF to air =1.
	17.2	199.2	526.3	g/t Zn produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Zn ratio 1.72–2.63 (intermediate value 1.90)
Proposed revision to UNEP Toolkit	5	65	130	g/t concentrate used		Proposed input factor for high mercury content concentrates; DF to air =1.
		16				Proposed input factor for low Hg content concentrates (from asymmetric distribution plot)
	8.6	123.3	342.1	g/t Zn produced		Adjusted using concentrate/Zn ratio 1.72–2.63 (intermediate value 1.90)
		30.3				Adjusted from 16 g/t in concentrate (from asymmetric distribution plot)
Abated EF						
2005 inventory		7		g/t Zn produced	AMAP/UNEP, 2008	
EMEP/EEA	2	5	8	g/t Zn produced	EMEP/EEA, 2009	Abatement not specified
	1.5	4.5	14			FF (+AP)
UNEP Toolkit abated input to air	1.0	10.5	20.0	g/t concentrate used	UNEP, 2011b	Default input factor 10–200 g/t. Dedicated Hg removal techniques. DF = 0.1
	1.7	19.9	52.6	g/t Zn produced	UNEP, 2011b; BREF, 2009	UNEP TK numbers adjusted using concentrate/Zn ratio 1.72–2.63 (intermediate value 1.90).
Proposed revision to UNEP Toolkit	4.5	58.5	117.0	g/t concentrate used		Default input factor 5–130 g/t. Coarse, dry PM retention. DF = 0.9
	2.5	31.9	63.7			Default input factor 5–130 g/t. Wet gas cleaning. DF = 0.49
	0.5	6.5	13.0			Default input factor 5–130 g/t. Wet gas cleaning + acid plant. DF = 0.1
	0.1	1.3	2.6			Default input factor 5–130 g/t. Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02
	7.8	111.0	307.9	g/t Zn produced		UNEP TKR numbers adjusted using concentrate/Zn ratio 1.72–2.63. Coarse, dry PM retention. DF = 0.9
	4.2	60.4	167.6			Wet gas cleaning. DF = 0.49
	0.9	12.3	34.2			Wet gas cleaning + acid plant. DF = 0.1
	0.2	2.5	6.8			Wet gas cleaning + acid plant + Hg-specific abatement. DF = 0.02

Table A6.24. Technology profile applied for non-ferrous metal production: zinc.

Technology	Reduction efficiency, %			Degree of application, %					Source
	low	intermediate	high	Country group					
				1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None or simple particle filters		0				2.5	5	10	UNEP, 2010a, 2011b; BREF, 2009; Hylander and Herbert, 2008; Kim et al., 2010a; Li et al., 2010
Level 1: Simple APC: particle control only		10							
Level 2: Basic APC: particle control + WGC ^a		50				2.5	5		
Level 3: Efficient APC: particle control + WGC + AP ^b		95		20	100	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX ^c + AP		99		80					
COUNTRY-SPECIFIC PROFILE									
China									
None (artisanal production)		0				2.3			National comments
APC but no acid production		50				9.9			
APC with acid production		95				77.4			
APC with acid production and mercury removal tower		98				10.4			
Republic of Korea									
ESP/Sulphuric acid process/Gas scrubber		99.9		100					Kim et al., 2010a

^a Particle control = cyclones and ESP, WGC = Wet gas cleaning; ^b integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; ^c Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Nor zinc process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 90%.

Non-ferrous metal production: mercury (Hg) dedicated production from cinnabar ore

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary Hg production from cinnabar ore; restricted to countries with primary mine production.

Applied UEFs. These are shown in Table A6.25.

Comparative EFs. These are shown in Table A6.26.

Discussion of EFs. In the absence of any additional/new national information, the UNEP Toolkit factors were adopted in this work.

The following literature sources were studied: UNEP (2011b), BREF (2009), Streets et al. (2011).

Basic assumptions during calculations of UEF:

- Mining and concentrating processes are not considered due to lack of data.

For all EFs, distribution factor = 0.25 (as in UNEP TK, applied to total Hg release during the process).

Applied technology profile. This is shown in Table A6.27.

Discussion of technology profile. Minimal abatement in

the form of basic particle matter control was assumed; production is in Group 3, 4 and 5 countries only.

Comparison with UNEP Toolkit factors. The default factor used (7500 g/t Hg produced) is the same as the factor in UNEP Toolkit.

Potential for double counting. The UNEP Toolkit EF, used as a generic value also in this work, is derived based on analysis of Hg concentrations in ore, concentrates and reject materials. The same principle was applied to country-specific EFs. Fuels are not included so there is no risk of double counting.

Comparison with 2005 inventory factors. The default unabated EF used (7500 g/t Hg produced) is based on a UNEP Toolkit analysis which assumes ≈430 t of ore mined per 1 t of Hg produced. This would correspond to about 17.5 g/t ore mined which is ten times lower than the abated EF of 200 g Hg/t ore mined that was used in the 2005 inventory calculations.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.25. Unabated emission factors (UEFs) applied for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		7500		g/t Hg produced	UNEP, 2011b	The UNEP Toolkit factor has been adopted.

Table A6.26. Comparative emission factors (EFs) for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit unabated input to air	5000	7500	10000	g/t Hg produced	UNEP, 2011b	DF = 0.25, total Hg released = 20–40 kg/t Hg produced. DF applies here to Hg releases, not total Hg input (1020–1040 kg/t Hg produced). Since no information on control systems is found, the UNEP Toolkit EF is considered as unabated.
Abated EF						
2005 inventory		200		g/t ore mined	AMAP/UNEP 2008	

Table A6.27. Technology profile applied for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

Technology	Reduction efficiency, %			Degree of application, %					Source
	low	intermediate	high	Country group					
				1	2	3	4	5	
Default profile									
Level 0: None		0							
Level 1: PM control		10		100	100	100	100	100	

Non-ferrous metal production: aluminium (Al) production from bauxite ore

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning primary Al production from bauxite.

Applied EFs. These are shown in Table A6.28.

Comparative EFs. These are shown in Table A6.29.

Discussion of EFs. National data on material consumption and/or Hg contents was used instead of generic values wherever possible.

The following literature sources were studied: UNEP (2011b), Nelson et al. (2009), BREF (2009), national comments from China.

Basic assumptions during calculations of UEF:

- Emissions from Al production assume production of alumina from bauxite
- Digestion of bauxite is considered to be major source of Hg emissions

- Fuels can be a source of significant Hg inputs but these inputs are not included in the EFs.

Since Al is also produced from alumina, which is traded internationally, the emission factor for production of Al from bauxite was only applied to major bauxite-producing countries. In other Al-producing countries a lower EF was applied (empirically-derived from reported emissions and production statistics and comparable with EFs employed in some national inventories). In the former case, the EF may be underestimated as it does not account for the emissions associated with Al production from alumina. Information regarding the basis for Al production (i.e. bauxite vs. alumina) in different countries is generally not available.

Applied technology profile. This is shown in Table A6.30.

Discussion of technology profile. The following literature sources were studied: UNEP (2011b), Nelson et al. (2009), BREF (2009), national comments from China.

Comparison with UNEP Toolkit factors. The default factor used (0.32 g/t Al produced) is (rounded) equivalent to the default factors from the UNEP Toolkit (with adjustment for the application to Al production activity data rather than bauxite ore used).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in bauxite ore. Country-specific EFs are derived based on the same

principle. Fuels are not included so there should be no potential for double counting.

Comparison with 2005 inventory factors. Production of Al was not included in the 2005 inventory.

Gaps/needs to improve factors and profiles. (1) Information on the basis for national production of Al (alumina vs. bauxite). (2) Information base for assumptions regarding technology profiles.

Table A6.28. Unabated emission factors (UEFs) applied for non-ferrous metal production: aluminium production from bauxite ore.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor						
Applied to major bauxite-producing countries	0.04	0.32	0.7	g/t Al produced	UNEP, 2011b; BREF, 2009	Expert evaluation based on UNEP, 2011b; BREF, 2009; Nelson et al., 2009 and country-specific data
Applied to Al-producing countries without major bauxite production		0.05				
Sub-Saharan African countries	0.11	0.13	0.14			
China	0.04	0.30	0.57			National data: 2 t bauxite/t alumina

Table A6.29. Comparative emission factors (EFs) for non-ferrous metal production: aluminium production from bauxite ore.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	0.01	0.08	0.15	g/t bauxite used	UNEP TK	Default input factor (Hg content of bauxite) 0.07–1 g/t; DF to air = 0.15.
	0.04	0.32	0.70	g/t Al produced	UNEP TK, Nelson et al., 2009; national comments for China, BREF	UNEP TK numbers are adjusted using bauxite/aluminium ratio ≈3.8–4.7 (2–2.46 t bauxite/t alumina (Nelson et al., 2009; national comments for China) × 1.9 t alumina/t Al (BREF, 2009))

Table A6.30. Technology profile applied for non-ferrous metal production: aluminium production from bauxite ore.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	Low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None		0					100	100	UNEP, 2011b; Nelson et al., 2009
Level 1: Particle control (cyclones+ ESP/FF) + WS		50			100	100			
Level 2: particle control (cyclones+ ESP/FF) + WS + Hg collection/reduction		75		100					
COUNTRY-SPECIFIC PROFILE									
China									
Cyclone + ESP/FF		60				100			National comments

Cement production

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning production of cement.

Applied UEFs. These are shown in Table A6.31.

Comparative EFs. These are shown in Table A6.32.

Discussion of EFs. During compilation of unabated country-specific EFs, an effort was made to use as much national data as possible. Most of the countries do not have complete mass balances but national data on material consumption and/or Hg contents was used instead of generic values wherever possible.

The following literature sources were studied: UNEP (2011b), BREF (2010), national comments and pers. comms. (Hagström, Maioli, Seo and Pudasainee, Solórzano, Suzuki); UNEP (2010a; report and answers to the questionnaire by Barbados, Brazil, China, Cyprus, Iceland, South Africa, USA), CSI (2005), Nelson (2007), Nelson et al. (2009), CEMBUREAU (2010), Kim et al. (2010a), Masekoameng et al. (2010), Streets et al. (2009, 2011), Tsinghua University, 2006; IEA, 2004; CEMENTA; PCA, 2008; COWI; Senior, 2010.

Basic assumptions during calculations of UEF:

- Only clinker formation stage is considered; subsequent mixing stage is assumed to make insignificant input into Hg emissions compared to the thermal processes according to UNEP (2011b), with the exception of fly ash addition during mixing which is not accounted for
- About 20% of the Hg input goes to the product (cement) (UNEP, 2011b)
- Recycling of filter materials on-site is not considered for UEF since recycling is only possible if abatement is present.

Fuel consumption: 0.079 t of petroleum coke (BREF) or 0.15–0.2 t coal (UNEP TK) per 1 t of cement. For countries that provided data on country-specific fuel consumption, fuel use per t of cement is based on this data and can include other energy sources such as biomass, natural gas, electrical energy from hydropower, etc.

Raw materials – input to the raw mill – are assumed to be 100% limestone. Significant amount of other raw materials can result in different input and emission factors. For countries that provided data on country-specific raw material consumption, this data was used in calculations.

Range of Hg content of materials used for UEF based on BREF mass balance:

- Petroleum coke: 0.01–0.71 g/t, intermediate value – 0.05 g/t (CEMBUREAU, 2010; country-specific data)
- Waste: 0.06–2.77 g/t, intermediate value – 0.32 g/t (CEMBUREAU, 2010; country-specific data)
- Limestone: 0.005–0.4 g/t, intermediate value – 0.09 g/t (CSI, 2005; CEMBUREAU, 2010; BREF, 2010; UNEP,

2011b; country-specific data)

- Coal: 0.05–0.5 g/t, intermediate value – 0.1 g/t (UNEP, 2011b; CEMBUREAU, 2010; country-specific data)
- Heavy fuel oil: 0.001–0.006 g/t, intermediate value – 0.0035 g/t (CEMBUREAU, 2010; Suzuki, pers. comm.)
- Clay: 0.002–0.45 g/t, intermediate value 0.23 g/t (CSI, 2005; CEMBUREAU, 2010)
- Shale: 0.05–0.3 g/t, intermediate value 0.175 g/t (CSI, 2005).

The range of Hg content of co-incinerated waste is quite wide, and using arithmetic average as an intermediate value can result in overestimation of Hg input into the process with co-incinerated waste.

For certain countries, there is data on limit values for Hg content of waste to be used as raw material in cement sector (BREF, 2010). For these countries, the limit values were used to determine high-end Hg content. For countries where low limit values are applied but no data on it can be found in BREF, 2010; there is a possibility for overestimation of UEF due to higher Hg content of waste assumed than it is in reality. For all EFs, distribution factor = 0.8 (the rest is going to the product according to UNEP, 2011b).

Clinker to cement ratio = 0.8 (BREF, 2010).

For cases with waste co-incineration, assumption on 12% thermal substitution of conventional fuel by waste was chosen based on the average value for EU (CSI, 2005).

Applied technology profile. This is shown in Table A6.33.

Discussion of technology profile. For countries with data on dust recycling back to the cement kiln, removal efficiencies are assumed to be 50% lower than generic or country-specific numbers for the same types of technologies based on APC outlet/inlet ratios of Hg concentrations or flows. This is because dust recycling results in an increased part of the Hg ultimately emitted to the air (UNEP, 2011b) even though in this case removal efficiency cannot be defined as outlet to inlet ratio. Number 50% is based on distribution factors presented in the UNEP Toolkit for cases with and without dust recycling (particle control only applied).

The following literature sources were studied: UNEP (2011b), BREF (2010), CEMBUREAU (2010), national comments and pers. comms. (Hagström, Maioli, Solórzano, Suzuki); Kim et al. (2010a), Nelson et al. (2009), Pudasainee et al. (2009a), UNEP (2010a; report and answers to the questionnaire by South Africa, UK, USA), Masekoameng et al. (2010), COWI; Theloke et al., 2008; NESHAP, 2010; Senior, 2010; US EPA, 2008.

Comparison with UNEP Toolkit factors: The default factor used for cement produced using coal, oil, gas or renewables as fuel without waste co-incineration (0.088 g Hg/t cement) is the same as the Toolkit default factor. Fuel is excluded in both cases.

The default factors used for cement produced using petroleum coke as fuel (0.15 g Hg/t cement) is higher than the Toolkit default factor (0.088 g/t cement) due to inclusion of the petroleum coke combustion.

The default factor used for coal, oil, gas or renewables as fuel with waste co-incineration (0.22 g Hg/t cement) is based on the BREF mass balance and is somewhat lower than the Toolkit default factor with waste co-incineration (0.352 g Hg/t cement). Fuel contributions are excluded in both cases and waste contributions are included.

Potential for double counting: Generic EFs for cement production compiled by the Swedish Environmental Institute (IVL) based on the BREF mass balance includes use of petroleum coke (for countries when petroleum coke is the main fuel) and waste co-incineration (for countries where waste co-incineration exists). By default, 12% thermal substitution of conventional fuel by waste is assumed in

countries with waste co-incineration. EFs used do not include coal and oil, which are accounted in separate sectors (coal and oil combustion in power plants and industry) so that there should be no double counting.

Country-specific EFs are derived using the same principle. However, in cases when the reported numbers are used, these numbers can include use of coal and oil so there is a possibility of double counting for these countries.

Comparison with 2005 inventory factors. The default factor applied when calculating emissions in 2005 (0.1 g Hg/t cement) is a global average abated factor that includes all possible fuels. The default factors used in the current inventory are unabated and differentiated by fuels, which is why most of them are higher but one (0.088 g Hg/t cement for coal without waste co-incineration) is slightly lower than 2005 factors.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.31. Unabated emission factors (UEFs) applied for cement production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factors						
Limestone only	0.003	0.087	0.4	g/t cement		Based on UNEP, 2011b; BREF, 2010 and country-specific data. Applicable if main fuel is coal, oil, gas or renewable source (excluded) and there is no waste co-incineration.
Limestone + waste	0.05	0.118	0.8			Based on UNEP, 2011b; BREF, 2010 and country-specific data. Applicable if main fuel is coal, oil, gas or renewable source (excluded) and there is waste co-incineration (included).
Limestone + petroleum coke, no waste co-incineration	0.005	0.091	0.6	g/t cement		Based on UNEP, 2011b; BREF, 2010 and country-specific data. Applicable if main fuel is petroleum coke (included) and there is no waste co-incineration.
Limestone + petroleum coke + waste	0.01	0.105	1.5			Based on UNEP, 2011b; BREF, 2010 and country-specific data. Applicable if main fuel is petroleum coke (included) and there is waste co-incineration (included).
Australia	0.005	0.102	0.631	g/t cement	CSI, 2005; BREF, 2010; Nelson, 2007; UNEP, 2011b; CEMBUREAU, 2010	National data: 6% energy substitution by waste; 0.05 g Hg/t coal (coal excluded).
Austria	0.008	0.203	2.246	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 46% energy substitution by waste. Coal (excluded).
Barbados	0.019	0.146	0.576	g/t cement	UNEP 2010a; BREF, 2010; CSI, 2005; CEMBUREAU, 2010	Country-specific fuel mix: 1.33 t limestone + 0.32 t shale + 0.13 t petroleum coke/t cement.
Belarus	0.005	0.085	0.165	g/t cement	BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 0.005–0.17 g Hg/t limestone. Coal (excluded).
Belgium	0.007	0.163	1.560	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 30% energy substitution by waste. Coal (excluded).
Brazil	0.023	0.037	0.249	g/t cement	Maioli, pers. comm.; UNEP 2010a; BREF, 2010; CEMBUREAU, 2010	National data: 10% energy substitution by waste; petroleum coke (included) accounts for 70% of energy demand, the rest is charcoal and electricity from hydro-energy. Hg content of charcoal is unknown and therefore charcoal is not included. 1.4 t limestone/t cement. 0.02 g Hg/t limestone.
China	0.005	0.087	0.389	g/t cement	UNEP 2010a, 2011b; BREF, 2010; CEMBUREAU, 2010	National data: 0.157 t coal/t cement. Coal is the main fuel (80% of total fuel consumption), here assumed as 100% (excluded).
Cyprus	0.006	0.141	0.535	g/t cement	UNEP 2010a, 2011b; CEMBUREAU, 2010; BREF, 2010	Country-specific mix: 1.03 t limestone + 0.33 t clay + 0.02 t coal + 0.1 t petroleum coke + 0.01 t oil + 0.02 t waste/t cement. Coal and oil excluded.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Czech Republic	0.006	0.148	1.358	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 24% energy substitution by waste. Coal (excluded).
Denmark	0.010	0.020	0.171	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 4% energy substitution by waste; 0.01 g Hg/t limestone. Coal (excluded).
Finland	0.005	0.095	0.510	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 3% energy substitution by waste. Coal (excluded).
France	0.007	0.173	1.765	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 34% energy substitution by waste. Coal (excluded).
Germany	0.008	0.171	0.861	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 42% energy substitution by waste; 0.005–0.13 g Hg/t limestone; max 1.2 g Hg/ t waste. Coal (excluded).
Hungary	0.005	0.095	0.510	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 3% energy substitution by waste. Coal (excluded).
Israel		0.091		g/t cement		Generic factor for production based mainly on petroleum coke applied
Japan		0.074		g/t cement	Suzuki, pers. comm.	Country-specific mix and Hg content. Coal and fuel oil excluded.
Iceland	0.005	0.087	0.389	g/t cement	UNEP 2010a; BREF, 2010; CEMBUREAU, 2010	National data: 0.17 t coal/t cement; 0.08 g Hg/ t coal. Coal is main fuel (excluded)
Italy	0.005	0.093	0.473	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 2% energy substitution by waste. Petroleum coke (included). National data: 2% energy substitution by waste. Coal (excluded).
Republic of Korea	0.045	0.123	0.187	g/t cement	Kim et al., 2010a; Seo, pers. comm.	UEF reported in Kim et al., 2010a are re-calculated based on country-specific clinker/cement ratio = 0.95. Fuels (coal, waste (19%), oil) are included.
Luxemburg	0.007	0.150	1.398	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 25% energy substitution by waste. Coal (excluded).
Mexico	0.005	0.075	0.358	g/t cement	Solórzano, pers. comm.; BREF, 2010; CEMBUREAU, 2010; UNEP, 2011b	Country-specific mix: 1 t limestone + 0.01 t coal + 0.06 t petroleum coke + 0.01 t oil + 0.002 t waste/t cement. Coal and oil excluded.
Morocco		0.091		g/t cement		Generic factor for production based mainly on petroleum coke applied
Netherlands	0.008	0.188	2.015	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 83% energy substitution by waste. Production based on petroleum coke (included).
Norway	0.007	0.175	1.802	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 35% energy substitution by waste. Petroleum coke (included). National data: 35% energy substitution by waste. Coal (excluded).
Poland	0.005	0.090	0.429	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 1% energy substitution by waste. Coal (excluded).
Russia	0.031	0.033	0.075	g/t cement	BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 0.031 g Hg/t limestone. Petroleum coke (included).
South Africa	0.005	0.106	0.689	g/t cement	UNEP, 2010a, 2011b; Masekoameng et al., 2010; BREF, 2010; CEMBUREAU, 2010	National data: 0.31 g Hg/t coal. Waste co-incineration (12% by energy assumed). Coal is main fuel (excluded).
Spain	0.005	0.091	0.441	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 1.3% energy substitution by waste. Coal (excluded).
Sweden	0.007	0.093	0.472	g/t cement	Hagström, pers. comm.; BREF, 2010; CEMBUREAU, 2010; UNEP, 2011b	Country-specific fuel mix: 0.07 t coal + 0.02 t petroleum coke + 0.03 t waste/t cement. Coal excluded.
Switzerland	0.032	0.149	1.959	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 48% energy substitution by waste; 0.03 g Hg/t limestone. Coal (excluded).
UK	0.005	0.103	0.631	g/t cement	CSI, 2005; BREF, 2010; UNEP, 2011b; CEMBUREAU, 2010	National data: 6% energy substitution by waste. Coal (excluded).
USA	0.005	0.064	1.391	g/t cement	UNEP 2010a; BREF, 2010; CEMBUREAU, 2010; PCA, 2008	Country-specific mix: 1.12 t limestone + 0.1 t coal + 0.03 t petroleum coke + 0.01–0.17 t waste/t cement. 0.005–1.12 g Hg/t limestone, 0–0.05 g Hg/t petroleum coke, 0.09 g Hg/t coal (excluded).

Table A6.32. Comparative emission factors (EFs) for cement production.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit unabated input to air, no waste co-incineration	0.016	0.088	0.16	g/t cement	UNEP, 2011b	Default input factor 0.02–0.2 g/t; DF to air = 0.8.
UNEP Toolkit unabated input to air, waste co-incineration	0.064	0.352	0.64		UNEP, 2011b	Default input factor 0.08–0.8 g/t; DF to air = 0.8. Percentage of co-incinerated waste unknown.
Based on BREF mass balance (limestone + petroleum coke, no waste co-incineration)	0.006	0.091	0.433		BREF, 2010; UNEP, 2011b; CSI, 2005; CEMBUREAU, 2010; IEA, 2004	Main fuel is petroleum coke (included) and there is no waste co-incineration.
Based on BREF mass balance (limestone + petroleum coke + waste)	0.006	0.105	0.662			Main fuel is petroleum coke (included) and there is waste co-incineration (included). 12% thermal substitution by waste assumed. Energy demand is based on petroleum coke use.
Based on BREF mass balance (limestone only)	0.005	0.087	0.389			Main fuel is coal, oil, gas or renewable source (excluded) and there is no waste co-incineration.
Based on BREF mass balance (limestone + waste)	0.006	0.118	0.873			Main fuel is coal, oil, gas or renewable source (excluded). 12% thermal substitution by waste assumed (included). Energy demand is based on coal use.
Abated EF						
2005 inventory	0.1			g/t cement	AMAP/UNEP, 2008	
UNEP Toolkit abated input to air, waste co-incineration	0.264				UNEP, 2011b	Default input factor 0.08–0.8 g/t. PM control with general ESP, or PS. DF = 0.6
	0.176					Default input factor 0.08–0.8 g/t. PM control with FF, or other with highly efficient PM retention. DF = 0.4
	0.308					Default input factor 0.08–0.8 g/t. PM control with recycling of dust. DF=0.7
CEMBUREAU	0.035			CEMBUREAU, 2010		
BREF	0.000	0.035	0.069	g/t clinker	BREF, 2010	European kilns. Numbers in BREF are presented as intervals. Intermediate value here is an arithmetic average.

Table A6.33. Technology profile applied for cement production.

Technology	Reduction efficiency, %			Degree of application, %					Source
	Country group								
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None	0					20	50	100	BREF, 2010; UNEP, 2010a, 2011b; CEMBUREAU, 2010; Pudasainee et al., 2009a; Theloke et al., 2008; NESHAP, 2010; Senior, 2010; US EPA, 2008
Level 1: Particulate matter simple APC: FF/ESP/PS	25			80	80	80	50		
Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF	55			15	20				
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR	75			4					
Level 4: Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR	95			1					
COUNTRY-SPECIFIC PROFILE									
Australia									
ESP	63					50			Nelson et al., 2009
FF	92					50			
Brazil									
PM: ESP or PS	25					50			Maioli, pers. comm.
PM: FF or other highly efficient PI FF	25					50			
EU25 (if not separately listed)									
Level 1: Particulate matter simple APC: FF/ESP/PS	25			39					Group 1 default adjusted to reflect increased controls due to regulation associated with increased use of co-incineration of waste
Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF	55			30					
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR	75			30					
Level 4: Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR	95			1					
Japan									
Particulate matter simple APC: FF/ESP/PS	25			80					National inventory information
Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF	55			15					
Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR	75			4					
Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR	95			1					
Republic of Korea									
Optimised FF (FF + spray tower)	57.3			100					Kim et al., 2010a
Mexico									
PM control: FF, ESP, cyclones	25					100			Solórzano, pers. comm.;
Sweden									
FF+SNCR	55			28					National comments
FF + scrubber+ SNCR	75			72					
South Africa									
ESP	10					50			UNEP 2010a/P29 study data; Masekoameng et al., 2010
FF	50					50			

USA			UNEP 2010a/P29 study data
ESP	67	9	
FF	75	20	
ESP+DS	73	1.2	
ESP+SNCR	77	0.8	
FF+SNCR	50	4.3	
FF+WS	55	2.1	
FF+DS	72	4.9	
ESP+FGD	56	0.6	
FF+ scrubber+ SNCR	91	2.2	
ESP+FGD+SNCR	66	0.8	
unclassified	43	54	
UK			UNEP 2010a/P29 study data
Particulate matter	25	26	
FF+SNCR	50	27	
ESP+WS	55	8	
ESP+DS	73	39	

Oil refining

Basis for 2010 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning amount of crude oil refined.

Applied EFs. These are shown in Table A6.34.

Comparative EFs. These are shown in Table A6.35.

Discussion of EFs. Regional and global UEFs are based on weighted averages derived from national UEFs. The values used for regional/global Hg content of crude oils are generally similar to those suggested by IPIECA (2012). The use of 25% as the factor for emissions to air is higher than that suggested by IPIECA (8%, based on studies at five San Francisco Bay refineries, McGuire et al., 2009) but consistent with values given in UNEP (2011b; provided by Petroleum Association of Japan for Japanese refineries, and reported by US-EPA [Wilhelm et al., 2001] cited in IKIMP [2012]).

The following literature sources were studied: UNEP (2011b), BREF (2012b), EMEP/EEA (2009), IKIMP (2012), IPIECA (2012), Inoue, pers. comm., Wilhelm et al. (2007).

Basic assumptions during calculations of UEF:

- UEFs are based on information concerning Hg content of crude oils produced in different countries (mainly from Wilhelm et al., 2007 and Inoue, pers. comm.; and assume that 25% of the Hg in refined oil is emitted to air (UNEP, 2001b; IKIMP, 2012)
- Where a country's production exceeds its consumption, it is assumed that the refined oil is from national sources. Where national consumption exceeds production (or there is no national production) assumptions are made

regarding the proportions of the refined oil that are obtained from different (national, regional and global) sources, and use is made of national, regional and global UEFs accordingly

- The oil extraction stage and transport prior to refining is not included although these activities can potentially give rise to significant releases of Hg (UNEP, 2011b)
- Combustion of fuels in oil refineries is account separately as stationary combustion.

Applied technology profile. This is shown in Table A6.36.

Discussion of technology profile. It was assumed that APCDs are either absent at oil refineries, or are inefficient at reducing Hg emissions to air from this source.

Comparison with UNEP Toolkit factors. The default factor used (0.0034 g/t crude oil refined) is significantly lower than the UNEP Toolkit default factor of 0.038 g/t crude oil refined.

Potential for double counting. UEFs are derived from analysis of Hg concentration of (refined) crude oil. Fuels consumed at oil refineries are not included so there is no risk of double counting.

Comparison with 2005 inventory factors. Emissions from oil refining were not included in the 2005 inventory.

Gaps/needs to improve factors and profiles. Additional information on Hg content of oil from different sources (countries and fields), and on the volumes, sources and Hg content of the oil refined in different countries/refineries.

Table A6.34. Unabated emission factors (UEFs) applied for oil refining.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		0.0034				Weighted average of national estimates and their proportional contribution to global supply.
Argentina		0.004				16.1 mg Hg/t crude oil; DF=0.25
Australia, New Zealand		0.0022				2.3 mg Hg/t crude oil; DF=0.25; 50% national and 50% global supply
Canada		0.0019				3.6 mg Hg/t crude oil; DF=0.25; 70% national and 30% global supply
Malaysia		0.0094				37.7 mg Hg/t crude oil; DF=0.25
Norway		0.0049				19.5 mg Hg/t crude oil; DF=0.25
Russia		0.0008				3.1 mg Hg/t crude oil; DF=0.25
Thailand		0.148		g/t crude oil refined	Wilhelm et al., 2007; Inoue, pers. comm., UNEP, 2011b; IKIMP, 2012	593 mg Hg/t crude oil; DF=0.25
USA		0.0023				4.3 mg Hg/t crude oils; DF=0.25; 50% national and 50% global supply
Vietnam		0.0166				66.5 mg Hg/t crude oil; DF=0.25
Asia		0.0132				
Europe		0.0033				
Middle East		0.0004				Weighted average based on national estimates and their proportional contribution to global supply for countries within region.
North Africa		0.0033				
South and Central America		0.001				
Sub-Saharan Africa		0.0007				

Table A6.35. Comparative emission factors (EFs) for oil refining.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	0.001	0.038	0.075	g/t crude oil refined	UNEP, 2011b	Default input factor (Hg content of crude oil) 5–300 mg/t (mean value 55 mg/t); DF to air =0.25.
UEF based on BREF Hg concentrations	0.008	0.016	0.025	g/t crude oil refined	BREF, 2012b; UNEP, 2011b	Input factor (Hg content of crude oil) 30–100 mg/t (BREF, range); DF to air =0.25 (UNEP, 2011b).
Abated EF						
EMEP/EEA	0.002	0.0051	0.015	g/t crude oil refined	EMEP/EEA, 2009	Abatement not specified

Table A6.36. Technology profile applied for oil refining.

Technology	Reduction efficiency, %			Degree of application, %					Source
	low	intermediate	high	Country group					
				1	2	3	4	5	
DEFAULT PROFILE									
None		0		100	100	100	100	100	

Large-scale gold production

Basis for 2010 emission estimates. UEFs applied to activity data (see Annex 5) concerning mine production of gold in tonnes. Activity is the production of gold from large-scale mine production (and is not including ASGM production).

Applied EFs. These are shown in Table A6.37.

Comparative EFs. These are shown in Table A6.38.

Discussion of EFs.

Basic assumptions during calculations of UEF:

The UEF depends on:

- Amount of Au in ore (which determines the ratio of tonnes of ore needed to produce a tonne of gold)
- Mercury content of ores
- Distribution factor to air (proportion of Hg that is released to air).

The first two at least are likely to vary considerably from mine to mine; however as it was not possible in this work to consider emissions estimates on a mine-by-mine basis, a generic average UEF was applied with the following assumptions:

Amount of gold in ore = a (generic) value of 4 g Au/t ore was assumed, yielding a ratio of 250 000 tonnes ore for one tonne of gold. Figure A6.1 illustrates the development of exploited Au-ore grade over past years, which in itself can be expected to have resulted in considerable changes in factors applicable to Hg releases from large-scale gold production. Generally, Hg releases would be expected to increase if the Au-content decreases and the Hg-content of the ore remains the same – which is not necessarily the case – due to the increased amount of ore mined for a given production of gold.

Mercury content of ore = the UNEP Toolkit default value of 55 Hg g/t Au ore was used. For comparison, the UNEP Toolkit quotes a range of 10–100 g/t ore; UNEP Para-29 (UNEP, 2010a) reported values of 0.1–100 g/t ore, and US Para-29 sources (UNEP, 2010a) reported values of 0.1–30 g/t ore. In the current global inventory calculations, a (lower) Hg in ore value of 5.5 g Hg/t Au ore was used.

Distribution factor to air = 0.04 was used, adopted from the UNEP Toolkit (UNEP, 2011b).

On this basis, the (unabated) EF is = $5.5 \times 250\,000 \times 0.04 = 55\,000$ g Hg emitted/tonne gold produced.

Applied technology profile. This is shown in Table A6.39.

Discussion of technology profile. The UNEP Toolkit distribution factor to air (0.04) is based on US national data only, so it may be assumed that this relates to specific technologies and possible application of APC technologies employed in the United States. It was reported that in South Africa and Australia, at least, large-scale gold production does not include efficient APC technologies. For the global inventory, it was assumed that APCDs are not applied at plants processing mined gold.

Comparison with UNEP Toolkit factors. The UNEP Toolkit default factor is based on activity data for amounts of ore used (extracted) and therefore are not directly comparable with the UEF applied in this work to activity data on amounts of (mine) gold produced. However, the assumption of an ore Hg content of 5.5 g Hg/t Au ore – compared with the value of 55 g/t in the Toolkit factor – would imply that the UEF used in this work is significantly lower than the UNEP Toolkit default factor.

Potential for double counting. UEFs are derived from Hg and gold content of ores. Fuels consumed at gold production plants are not included so there is no risk of double counting.

Comparison with 2005 inventory factors. The default factor used in the current inventory is unabated, however since it was assumed that efficient Hg emission controls are not applied at gold production plants the factor used in this work (55 000 g/t gold) is higher than the (abated) EF of 25 000 g/t gold used in the 2005 inventory preparation.

Gaps/needs to improve factors and profiles. Relevant information on Hg and Au content of ores and concentrates processed in different countries, including the distribution of these factors for individual mines/processing facilities. Information on APCDs employed at large-scale gold production facilities.

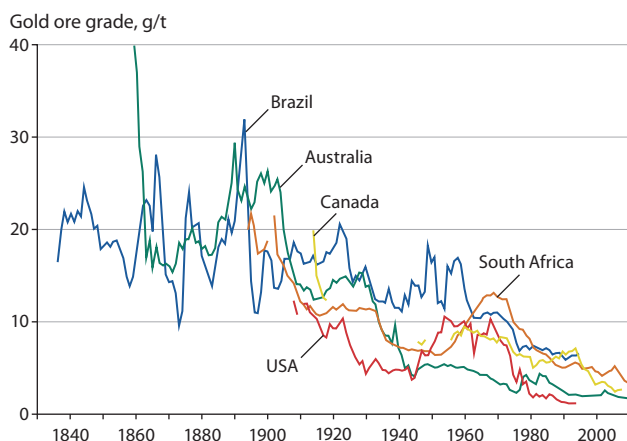


Figure A6.1. Changes in gold ore grade over time in different countries. Source: after Giurco et al., 2010.

Table A6.37. Emission factors applied for large-scale gold production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		55000		g/t (mine) Au produced	UNEP, 2011b	4 g Au/t ore; 5.5 g Hg/tonne Au ore; df 0.04

Table A6.38. Comparative emission factors (EFs) for large-scale gold production.

	Emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	0.4	2.2	4	g/t ore used (extracted)	UNEP, 2011b	Default input factor 55 (10–100) g/t ore used; DF to air = 0.04.
Abated EF						
2005 inventory		25000		g/t Au	AMAP/UNEP, 2008	

Table A6.39. Technology profile applied for large-scale gold production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
None		0		100	100	100	100	100	

Chlor-alkali industry

*Basis for 2010 emission estimates.*UEFs and technology employed to reduce emissions from this sector, applied to activity data (see Annex 5) concerning chlorine (Cl₂) production capacity (or production where available) using Hg-cell technology.

*Applied UEFs.*These are shown in Table A6.40.

*Comparative EFs.*These are shown in Table A6.41.

*Discussion of EFs.*The following sources were studied: UNEP (2011b), OSPAR (2011), national information received from: Argentina, Brazil, India (Corporate Responsibility for Environmental Protection [CREP] Charter); Romania, and LRTAP sources.

OSPAR (2011) reported ranges of Hg emissions in 2009 of 0.14–1.64 g/t Cl₂ with >90% to air. This is comparable to 2007 (0.17–2.68 g/t) with only five out of 30 plants still reporting emissions >1 g/t (compared to nine plants in 2007 and 17 plants in 2005) and most plants emitting between 0.5 and 1 g/t. Conversion to membrane technology and shutdown of plants is a more common option than the

reduction of emissions below the 0.5 g/t emission value. The emission average for all European plants (including the plants outside the OSPAR Convention area) is below 1 g/t. The one remaining Swedish plant was identified as the best performing Hg-based chlor-alkali plant in the OSPAR region.

*Applied technology profile.*This is shown in Table A6.42.

*Discussion of technology profile.*The EC Reference Document on Best Available Techniques in the Chlor-alkali Industry identifies the Hg-free membrane process as BAT. In as far as chlor-alkali production based on Hg-cell technology is concerned; much of the abatement potential lies in application of best practices and good management of operations. As such, technological abatement is represented as BAP in the technology profile, with reduction effectiveness based on reported national data largely for the OSPAR region. For India, information was used describing application within the chlor-alkali industry in India of the CREP Charter which incorporates: complete recycling of Hg-bearing effluent; treatment of cell-room ventilation gas; reduction of Hg in hydrogen gas; installation of salt washery unit; installation

of Hg distillation units; brine sludge treatment and disposal in secured landfill.

Comparison with UNEP Toolkit factors. In this work, the applied UEFs were based on the low-intermediate ranges of the UNEP Toolkit (UNEP, 2011b) default factors reflecting trends in reductions in Hg consumption in the chlor-alkali industry in recent years; this also converged estimates towards recently reported national emissions estimates for some countries. Recent research, however, indicates that commonly applied emission estimation approaches do not always include (potentially significant) fugitive emissions.

Potential for double counting. There is no identified potential

double counting associated with estimates for the chlor-alkali sector.

Comparison with 2005 inventory factors. The AEF applied in 2005 can be considered to reflect abated emissions in Europe (and other developed countries) at that time; these EFs have since been further reduced; however in other countries higher EFs are considered more applicable.

Gaps/needs to improve factors and profiles. Information on potential Hg releases associated with non-standard operating conditions (accidental releases) in developed countries, and improvements in applied technology and BAP in other countries.

Table A6.40. Unabated emission factors (UEFs) for the chlor-alkali industry.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		20		g/t Cl ₂ capacity	UNEP, 2011b	UNEP Toolkit low–intermediate (unaccounted consumption considered released)
Argentina	3.75	10	21.6	g/t Cl ₂ production		National comments (5.8 g/t): Intermediate: 57.88 g/t Cl ₂ produced (df 0.1); 15% of production; High: 215.97 g/t Cl ₂ produced (df 0.1); 3.3 % of production; Low: 15.34 g/t Cl ₂ produced (df 0.245); 82% of production
Brazil		10				
India		10			UNEP, 2011b	India (CREP) (7.5 g/t) and UNEP Toolkit low–intermediate
Italy		20			OSPAR, 2011	Based on OSPAR (2011)
Romania		5				National comments and UNEP, 2011b
Sweden		0.5			OSPAR, 2011	Based on OSPAR (2011)
OSPAR countries (Belgium, Finland, France, Germany, Spain, Switzerland) excluding the UK		2.5			OSPAR, 2011	Based on OSPAR (2011) and UNEP Toolkit (with assumed on-/off-site storage/recycling/ dumping)
Other Group 1 and 2 countries		5		g/t Cl ₂ capacity	UNEP, 2011b	UNEP Toolkit low (with assumed on-/off-site storage/recycling/ dumping)
Group 3 countries		10			UNEP, 2011b	UNEP Toolkit low–intermediate (with assumed on-/off-site storage/recycling/ dumping)

Table A6.41. Comparative emission factors for the chlor-alkali industry.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
	5	42	80	g/t Cl ₂ produced	UNEP, 2011b	For production using Hg-cell technology; 0.2 of total release is to air (unaccounted consumption considered released)
	2.5	21	40	g/t Cl ₂ produced	UNEP, 2011b	For production using Hg-cell technology; 0.1 of total release is to air (with assumed on-/off-site storage/ recycling/ dumping)
	2.2	18.6	35.5	g/t NaOH produced	UNEP, 2011b	For production using Hg-cell technology; (with assumed on-/off-site storage/recycling/ dumping). For conversion between a Cl ₂ -basis and an NaOH basis, the following factor can be used: g/t NaOH = g/t Cl ₂ /1.128 (based on European Commission, 2001b cited in UNEP, 2011b)
Abated EF						
2005 inventory	2.5		g/t NaOH produced	AMAP/UNEP 2008	Would correspond to 2.82 g/t Cl ₂ produced	
Belgium	0.5		g/t Cl ₂ capacity	OSPAR, 2011		
Finland	0.9					
France	0.8					
Germany	0.7					
India	2		g/t NaOH produced		India (CREP) has a target of 2 g/t NaOH production	
Spain	0.5		g/t Cl ₂ capacity	OSPAR, 2011		
Sweden	0.15					
Switzerland	0.4					
United Kingdom	1.5					

Table A6.42. Technology profile applied for the chlor-alkali industry.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
None		0					100	100	
Advanced BAP		50		100	100	100			
COUNTRY-SPECIFIC PROFILE									
India		50						100	

Annex 7: Comparison of calculated and reported national emission estimates for 2010

Important notes

Global inventory emission estimates presented in the following tables are taken directly from database and spreadsheet calculations; implied precision should be ignored and numbers should not be read to more than three significant figures.

The term ‘Other waste’ includes emissions from breakage during product use, recycling, uncontrolled incineration and controlled and uncontrolled landfill. The term ‘Waste incineration’ (at least as far as the ‘Estimated abated (controlled) emission’ column is concerned) is ‘Controlled incineration’.

Direct alignment between sectors used in the global inventory and those used in national and other reporting systems (including LRTAP reporting) is complicated and not always possible (see comments in Section 2.3.2). This is reflected in some of the tables below (e.g. for Denmark, Table A7.5; Finland, Table A7.6; France, Table A7.7; Italy, Table A7.8; Norway Table A7.12; Sweden, Table A7.13) where it can be problematic to translate LRTAP based-reporting to the UNEP inventory sector categories. Some relevant comments are included in table annotations; however, an exact comparison of values would require a more careful analysis of supplementary information included in some national and other reporting systems.

Table A7.1. **Australia.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate ^a , kg
Stationary fossil fuel combustion in (major) power plants (SC-PP):	Coal	3168.0 (2106.7 – 4530.2)	675
	Oil	6.8 (3.2 – 11.2)	
	Gas	3.0 (1.4 – 4.9)	
Stationary fossil fuel combustion in industrial uses (SC-IND):	Coal	177.0 (117.7 – 253.2)	46.6
	Oil	22.0 (10.4 – 36.3)	
	Gas	1.9 (0.9 – 3.1)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR):	Coal	7.0 (4.7 – 10.0)	42.8
	Oil	26.7 (12.7 – 44.0)	10.5 + 1.2 + 0.4
	Gas	1.0 (0.5 – 1.7)	12.2
Production of iron and steel (PISP)		15.1 (6.6 – 28.8)	347
Non-ferrous metal production (NFMP):	Copper	812.8 (289.8 – 4068.4)	6766
	Lead	127.5 (44.6 – 248.6)	
	Zinc	3102.8 (1845.8 – 3427.9)	
	Gold (large-scale)	12210.0 (85.5 – 31746.0)	
	Mercury		
Aluminium		308.5 (121.5 – 639.1)	
Artisanal and small-scale gold mining (ASGM)		–	
Cement production (CEM)		598.2 (219.6 – 2794.4)	191
Caustic soda production (CSP)			
Oil refining (OR)		59.4 (28.2 – 97.9)	32.2
Cremation (CREM)		82.2 (18.5 – 308.4)	6.4
Waste (WAS):	Waste incineration	236.0 (70.8 – 708.0)	0.4
	Other waste	380.6 (106.7 – 1291.3)	19
Other			13452
		21346.4 (5095.8 – 50253.5)	21603

^a Information taken from national release inventory (NRI); categories used in the NRI are difficult to translate into sectors employed in the global inventory and therefore these comparisons should be considered very preliminary.

Table A7.2. **Argentina.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	66.6 (44.3 – 95.2)	159.8
Caustic soda production (CSP)		777.0 (369.1 – 1282.1)	360
Oil refining (OR)		103.1 (49.0 – 170.1)	354.3 ^a

^a Includes extraction.

Table A7.3. **Brazil.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	478.6 (301.5 – 684.4)	1000
Caustic soda production (CSP)		1117.0 (530.6 – 1843.1)	1196.6
Oil refining (OR)		90.5 (40.7 – 149.2)	1300 ^a

^a Includes extraction.

 Table A7.4. **Canada.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	2145.4 (1426.7 – 3067.9)	1488
	Oil	30.9 (14.7 – 50.9)	
	Gas	5.3 (2.5 – 8.8)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	126.3 (84.0 – 180.7)	^a
	Oil	23.9 (11.4 – 39.5)	
	Gas	–	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	11.8 (7.9 – 16.9)	
	Oil	88.6 (42.1 – 146.2)	154.2 ^b
	Gas	–	
Production of iron and steel (PISP)		196.6 (82.6 – 1405.9)	181.5 ^c
Non-ferrous metal production (NFMP):	Copper	46.7 (25.9 – 91.5)	
	Lead	12.4 (6.8 – 19.5)	540 ^d
	Zinc	315.9 (192.6 – 2801.5)	
	Gold (large scale)	267.8 (1.9 – 696.2)	200
	Mercury		0
	Aluminum	37.0 (13.0 – 72.2)	22
Artisanal and small-scale gold mining (ASGM)		–	0
Cement production (CEM)		420.5 (152.3 – 1530.0)	288.8 ^c
Caustic soda production (CSP)			
Oil refining (OR)		129.3 (61.4 – 213.3)	195
Cremation (CREM)		91.0 (24.9 – 305.0)	253.6 ^e
Waste (WAS)	Waste incineration	138.6 (33.2 – 499.5)	700.3
	Other waste	382.0 (91.5 – 1376.3)	
Other	Other ^f		866
	Additional ^f		332
		4470.1 (2275.3 – 12521.9)	5222

^a Included elsewhere; ^b includes biomass fuels; ^c includes fuel combustion emissions; national emissions estimate for primary + secondary iron and steel production = 410 kg; ^d Canada's main Hg emission source, a copper smelting and refining facility, ceased operations in June 2010, reducing annual emissions by an estimated 630 kg; ^e based on US EPA emission factors; ^f 'Other' includes emissions from landfill, energy from waste gas facilities, sewage treatment plants, etc.; 'additional' is primarily from the Hg-containing products estimates along with small amounts from a variety of minor Hg industrial / commercial and residential sectors.

Table A7.5. **Denmark.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	343.4 (228.3 – 491.0)	130.5
	Oil	4.5 (2.1 – 7.4)	0.7
	Gas	0.6 (0.3 – 0.9)	7.4
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	8.8 (5.9 – 12.6)	15
	Oil	2.4 (1.1 – 4.0)	1.5
	Gas	0.2 (0.1 – 0.3)	4.0
Stationary fossil fuel combustion in domestic/residential/commercial uses (SC-DR)	Coal	6.6 (4.4 – 9.4)	8.6
	Oil	8.1 (3.8 – 13.3)	2.4
	Gas	0.2 (0.1 – 0.3)	4.7
Production of iron and steel (PISP)			8.8 ^a
Non-ferrous metal production (NFMP):	Copper		
	Lead		
	Zinc		
	Gold (large scale)		0
	Mercury		
	Aluminium		
Artisanal and small-scale gold mining (ASGM)			0
Cement production (CEM)		20.1 (10.6 – 124.9)	30
Caustic soda production (CSP)			0
Oil refining (OR)		26.5 (12.6 – 43.8)	20.2
Cremation (CREM)		8.1 (2.2 – 26.7)	47.1
Waste (WAS)	Waste incineration	20.8 (4.3 – 80.7)	72.2
	Other waste	57.3 (11.9 – 222.2)	
Other			
		507.4 (287.7 – 1037.5)	439.6 ^b

^a Includes secondary steel; ^b LRTAP reporting total. Note: Stationary combustion of other fuels, e.g. petroleum coke, wood, straw, biogas and LPG accounts for 35 kg. Mobile combustion (including tyre and brake wear) accounts for 45 kg. Other industrial processes account for 5.6 kg. The remaining contribution is from flaring, product use and other minor miscellaneous sources.

Table A7.6. **Finland.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	230.8 (153.5 – 330.0)	450 ^a
	Oil	8.2 (3.9 – 13.6)	
	Gas	0.6 (0.3 – 1.0)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	7.8 (5.2 – 11.1)	
	Oil	6.9 (3.3 – 11.3)	
	Gas	0.1 (0.1 – 0.2)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	0.9 (0.6 – 1.3)	
	Oil	11.0 (5.2 – 18.2)	
	Gas	0.0 (0.0 – 0.0)	
Production of iron and steel (PISP)		65.8 (27.6 – 470.2)	303 ^b
Non-ferrous metal production (NFMP):	Copper	265.2 (94.6 – 1327.6)	0
	Lead		
	Zinc	653.2 (245.4 – 1605.2)	2 ^c
	Gold (large scale)	19.3 (0.1 – 50.1)	^d
	Mercury		^d
	Aluminum		
Artisanal and small-scale gold mining (ASGM)			
Cement production (CEM)		83.6 (30.8 – 346.2)	36
Caustic soda production (CSP)		50.0 (17.5 – 97.5)	46 ^c
Oil refining (OR)		37.2 (17.7 – 61.4)	16 ^c
Cremation (CREM)		4.0 (1.1 – 13.2)	42
Waste (WAS)	Waste incineration	18.7 (3.9 – 72.4)	1
	Other waste	51.5 (10.7 – 199.6)	^d
Other	Undefined		
	Other		
		1514.8 (621.4 – 4630.2)	896

^a Includes all stationary combustion; ^b includes secondary production; ^c reporting by plants; ^d included elsewhere.

Table A7.7. **France.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	420.2 (279.4 – 600.8)	283
	Oil	29.9 (14.2 – 49.4)	30.3
	Gas	1.5 (0.7 – 2.5)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	144.8 (96.3 – 207.1)	495
	Oil	21.7 (10.3 – 35.8)	22.9
	Gas	1.5 (0.7 – 2.5)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	63.0 (41.9 – 90.1)	196
	Oil	97.7 (46.4 – 161.2)	195 ^a
	Gas	5.5 (2.6 – 9.0)	
Production of iron and steel (PISP)		260.0 (109.2 – 1859.1)	646
Non-ferrous metal production (NFMP):	Copper		–
	Lead		–
	Zinc	356.5 (133.9 – 875.9)	–
	Gold (large scale)	4.1 (0.0 – 10.7)	–
	Mercury		–
	Aluminium	4.5 (1.6 – 8.7)	1.07
Artisanal and small-scale gold mining (ASGM)			–
Cement production (CEM)		1592.4 (579.9 – 11595.4)	260
Caustic soda production (CSP)		860.8 (301.3 – 1678.5)	483
Oil refining (OR)		245.2 (116.5 – 404.7)	80.1
Cremation (CREM)		34.2 (9.2 – 113.0)	361
Waste (WAS)	Waste incineration	208.4 (43.4 – 808.3)	1056
	Other waste	574.2 (119.7 – 2227.2)	
Other	Combustion in industry (fuel undefined)		253
	Use of solvents		0.006
	Other		
		4926.2 (1907.3 – 20740.0)	4363

^a Includes 187 kg emissions from maritime mobile sources.

Table A7.8. **Italy.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2009, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	821.2 (546.1 – 1174.3)	699
	Oil	97.9 (46.5 – 161.5)	^a
	Gas	6.3 (3.0 – 10.3)	^a
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	28.6 (19.0 – 40.9)	^b
	Oil	30.8 (14.6 – 50.8)	
	Gas	2.3 (1.1 – 3.8)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	0.8 (0.5 – 1.1)	191
	Oil	69.6 (33.1 – 114.8)	^a
	Gas	6.1 (2.9 – 10.0)	^a
Production of iron and steel (PISP)		219.4 (92.2 – 1569.0)	
Non-ferrous metal production (NFMP):	Copper		2227
	Lead	3.4 (1.2 – 6.6)	
	Zinc	221.4 (83.2 – 544.1)	
	Gold (large scale)	1.2 (0.0 – 3.2)	
	Mercury		
	Aluminum	2.1 (0.7 – 4.1)	
Artisanal and small-scale gold mining (ASGM)			
Cement production (CEM)		1698.9 (626.6 – 6720.6)	1085
Caustic soda production (CSP)		420.0 (147.0 – 818.9)	
Oil refining (OR)		273.2 (129.8 – 450.8)	163
Cremation (CREM)		13.8 (3.7 – 45.7)	0.1
Waste (WAS)	Waste incineration	181.3 (37.8 – 703.1)	147
	Other waste	499.5 (104.1 – 1937.3)	
Other			3957
		4597.6 (1893.0 – 14370.9)	8614

^a Included in coal; ^b assumed to be included under other sectors (e.g. metal production, cement production).

Table A7.9. **Japan.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	882.3 (586.7 – 1261.7)	880–1000
	Oil	209.2 (99.3 – 345.1)	114
	Gas	12.8 (6.1 – 21.2)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	209.8 (139.5 – 300.0)	210
	Oil	87.8 (41.7 – 144.8)	7
	Gas	1.7 (0.8 – 2.8)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	30.9 (20.6 – 44.2)	67
	Oil	116.2 (55.2 – 191.7)	
	Gas	5.7 (2.7 – 9.4)	
Production of iron and steel (PISP)		4670.2 (3130.6 – 6328.5)	4200
Non-ferrous metal production (NFMP):	Copper	2983.4 (1443.6 – 12636.1)	940
	Lead	48.6 (23.1 – 80.2)	
	Zinc	1270.8 (647.8 – 2642.4)	
	Gold (large scale)	19.3 (0.1 – 50.1)	
	Mercury		
	Aluminium	0.1 (0.0 – 0.1)	
Artisanal and small-scale gold mining (ASGM)		–	
Cement production (CEM)		2749.4 (962.3 – 5361.4)	7200
Caustic soda production (CSP)			0
Oil refining (OR)		569.9 (270.7 – 940.4)	137
Cremation (CREM)		39.9 (11.1 – 126.9)	61
Waste (WAS)	Waste incineration	1078.3 (272.4 – 3716.1)	1930–5900 ^a
	Other waste	2242.1 (566.4 – 7726.8)	
	Sludge incineration	^b	170–850
Other			1324 ^c
		17228.4 (8280.8 – 41929.9)	17240–22010

^a Includes emissions associated with incineration of municipal waste (1200–1800 kg) and industrial waste (730–4100 kg, including some medical waste). Emissions from medical waste incineration are estimated at 310–1200 kg; ^b not evaluated; ^c emissions from limestone processing and ,manufacture of pulp and paper, carbon black, batteries and fluorescent lamps.

Table A7.10. **Republic of Korea.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	1123.9 (747.4 – 1607.2)	1415
	Oil	48.8 (23.2 – 80.5)	50
	Gas	3.0 (1.4 – 4.9)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal		
	Oil	1142.2 (542.6 – 1884.7)	
	Gas	1.3 (0.6 – 2.2)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	85.5 (56.9 – 122.3)	310
	Oil	91.4 (43.4 – 150.9)	
	Gas	2.9 (1.4 – 4.8)	
Production of iron and steel (PISP)		494.6 (461.8 – 553.5)	1370
Non-ferrous metal production (NFMP):	Copper	100.7 (48.7 – 426.5)	4
	Lead	60.0 (28.5 – 99.0)	5.6
	Zinc	100.3 (51.1 – 208.5)	6.8
	Gold (large scale)		
	Mercury		
	Aluminum		
Artisanal and small-scale gold mining (ASGM)		–	
Cement production (CEM)		2490.5 (1615.8 – 3452.3)	2960
Caustic soda production (CSP)			
Oil refining (OR)		374.1 (177.7 – 617.3)	1510
Cremation (CREM)		9.84 (2.73 – 31.3)	3.6
Waste (WAS)	Waste incineration	355.3 (89.8 – 1224.6)	404
	Other waste	738.8 (186.6 – 2546.1)	
		7223.4 (4079.7 – 13016.5)	8039

Table A7.11. **Mexico.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate ^a , kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	3358.2 (2233.2 – 4802.2)	3875
	Oil	179.2 (85.1 – 295.7)	38
	Gas	8.6 (4.1 – 14.2)	4
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	61.8 (41.1 – 88.4)	65
	Oil	62.5 (29.7 – 103.1)	13
	Gas	1.9 (0.9 – 3.2)	14
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	–	–
	Oil	35.1 (16.6 – 57.8)	0.4
	Gas	0.2 (0.1 – 0.3)	0.5
Production of iron and steel (PISP)		312.6 (145.9 – 791.9)	217+54 ^b
Non-ferrous metal production (NFMP):	Copper	2161.1 (1045.7 – 9153.2)	576
	Lead	210.1 (100.8 – 370.4)	933
	Zinc	5420.2 (2763.0 – 11270.0)	5098
	Gold (large scale)	2874.8 (27.3 – 6324.6)	1587
	Mercury		–
	Aluminium		
Artisanal and small-scale gold mining (ASGM)		3750.0 (937.5 – 6562.5)	–
Cement production (CEM)		2070.0 (1048.8 – 6572.9)	4830
Caustic soda production (CSP)		600.0 (210.0 – 1170.0)	2220 ^c
Oil refining (OR)		69.9 (33.2 – 115.4)	
Cremation (CREM)		113.6 (28.1 – 380.8)	355
Waste (WAS)	Waste incineration	14.2 (3.7 – 46.9)	262 ^c
	Other waste	2088.0 (542.9 – 6890.4)	
Other	Biomass combustion (heat/energy)	^d	78.9
	Geothermal energy	^d	298
		23391.9 (9297.6 – 55013.8)	20519

^a Updated from 2008 national inventory; provided by G. Solorzano (based on the 2010 Mexican Pollution Release and Transfer Register; SEMARNAT, 2010); ^b pig iron and steel plus petroleum coke combustion;

^c Year 2008; ^d not evaluated.

Table A7.12. **Norway.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	1.3 (0.9 – 1.9)	a
	Oil	0.4 (0.2 – 0.7)	
	Gas	1.0 (0.5 – 1.7)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	34.2 (22.7 – 48.9)	5
	Oil	2.5 (1.2 – 4.1)	63
	Gas	0.0 (0.0 – 0.1)	
Stationary fossil fuel combustion in domestic/ residential/commercial uses (SC-DR)	Coal	–	
	Oil	9.3 (4.4 – 15.4)	43.5
	Gas	0.0 (0.0 – 0.0)	
Production of iron and steel (PISP)		2.6 (1.1 – 18.3)	51 ^b
Non-ferrous metal production (NFMP):	Copper		
	Lead		
	Zinc	284.7 (190.2 – 441.8)	4
	Gold (large scale)		
	Mercury		
	Aluminum	10.0 (3.5 – 19.5)	0.2
Artisanal and small-scale gold mining (ASGM)		–	
Cement production (CEM)		145.2 (52.9 – 1066.5)	47
Caustic soda production (CSP)			
Oil refining (OR)		67.8 (32.2 – 111.8)	0.02 ^c
Cremation (CREM)		0.48 (0.1 – 1.6)	75 ^d
Waste (WAS)	Waste incineration	29.4 (7.6 – 100.3)	24 ^a
	Other waste	81.0 (20.9 – 276.4)	
Other	Mobile sources		213
		669.9 (338.4 – 2109.1)	583 ^e

^a Waste incineration: The national estimate represents emissions from energy supply, which is both waste incineration of waste, and stationary fossil fuel combustion in power plants; ^b includes ferroalloys; ^c includes only emissions from combustion for energy at refineries, which in the global inventory would be accounted under SC-IND; ^d includes fires in addition to cremation; ^e LRTAP reporting total.

Table A7.13. **Sweden.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2010, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate, kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	9.3 (6.2 – 13.2)	193 ^a
	Oil	4.8 (2.3 – 7.9)	
	Gas	0.1 (0.1 – 0.2)	
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	57.9 (38.5 – 82.8)	44 ^b
	Oil	11.2 (5.3 – 18.5)	
	Gas	0.1 (0.0 – 0.2)	
Stationary fossil fuel combustion in domestic/ residential/commercial uses (SC-DR)	Coal		32 ^b
	Oil	12.2 (5.8 – 20.1)	
	Gas	0.0 (0.0 – 0.1)	
Production of iron and steel (PISP)		88.4 (37.1 – 632.2)	73 ^c
Non-ferrous metal production (NFMP):	Copper	242.7 (86.5 – 1214.7)	45 ^d
	Lead	5.9 (2.0 – 11.4)	
	Zinc		
	Gold (large scale)	13.8 (0.1 – 35.8)	
	Mercury		–
	Aluminium	1.2 (0.4 – 2.3)	^e
Artisanal and small-scale gold mining (ASGM)			–
Cement production (CEM)		84.0 (31.6 – 331.5)	4
Caustic soda production (CSP)		30.0 (10.5 – 58.5)	16
Oil refining (OR)		66.8 (31.7 – 110.2)	
Cremation (CREM)		13.5 (3.7 – 44.7)	114
Waste (WAS)	Waste incineration	34.8 (7.2 – 134.9)	^f
	Other waste	95.8 (20.0 – 371.6)	
Other			
		772.3 (289.1 – 3090.7)	554 ^g

^a Heat and power production, including biofuels and waste; ^b including biofuels; ^c including 69 kg from secondary steel production; ^d primary and secondary production, including silver; ^e Sweden's only primary Al plant uses alumina as a raw material. No emissions were reported for 2010 or 2011. ^f included in SC-PP; ^g LRTAP reporting total for all sources.

Table A7.14. **United States.** Estimated abated (controlled) mercury emissions for 2010 and national estimates for 2008, for comparison.

Sector (code)		2010 inventory estimate; abated emission, kg	National estimate ^a , kg
Stationary fossil fuel combustion in (major) power plants (SC-PP)	Coal	36489.5 (24265.5 – 52180.0)	26776
	Oil	86.9 (41.3 – 143.4)	77.8
	Gas	50.9 (24.2 – 84.0)	^b
Stationary fossil fuel combustion in industrial uses (SC-IND)	Coal	4284.0 (2848.8 – 6126.1)	4401
	Oil	109.8 (52.1 – 181.1)	
	Gas	24.6 (11.7 – 40.6)	
Stationary fossil fuel combustion in other (domestic/residential; commercial; transport; etc.) uses (SC-DR)	Coal	391.7 (260.5 – 560.1)	10.7
	Oil	363.2 (172.5 – 599.2)	1074
	Gas	45.9 (21.8 – 75.8)	54.6
Production of iron and steel (PISP)		922.6 (409.7 – 2184.0)	577
Non-ferrous metal production (NFMP):	Copper	1149.8 (410.0 – 5755.6)	1112
	Lead	23.2 (8.1 – 45.2)	
	Zinc	53.3 (23.7 – 95.5)	
	Gold (large scale)	1368.5 (9.6 – 3558.0)	1569
	Mercury		0
	Aluminum	138.1 (54.4 – 286.1)	^c
Artisanal and small-scale gold mining (ASGM)		–	–
Cement production (CEM)		1848.0 (697.3 – 27308.4)	3779 ^d
Caustic soda production (CSP)		1092.5 (382.4 – 2130.4)	1223
Oil refining (OR)		1671.9 (794.2 – 2758.7)	362
Cremation (CREM)		437.8 (119.7 – 1467.9)	531
Waste (WAS)	Waste incineration	1520.5 (364.4 – 5478.9)	2458
	Other waste	4189.5 (1004.1 – 15096.2)	681
Other	Undefined		1034
	Secondary steel production (EAF + other)	^b	4530
	Secondary non-ferrous metal production	^b	294
	Sewage sludge incineration	^b	413
	Industrial pulp and paper	^b	236
	Rail	^e	674
	On road	^e	612
	Non-road		291
	Other		2827
		56262 (31976 – 126155)	55600

^a EPA National estimate from the 2008 NEI v2 inventory (<http://www.epa.gov/ttn/chief/net/2008inventory.html>).^b not evaluated; ^c included in non-ferrous (Cu, Pb, Zn) emissions estimate; ^d excludes cement kilns that burn hazardous waste (Hg from the kilns that burn hazardous waste are accounted for in the Waste incineration sector); ^e included in SC-DR.

Annex 8: Global Inventory Estimates 2010

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
ABW	Aruba	Central America and the Caribbean	CREM	CREM	0.018	0.072	0.241
ABW	Aruba	Central America and the Caribbean	WASOTH	WASOTH	1.224	4.706	15.531
ABW	Aruba	Central America and the Caribbean	WI	WI	0.004	0.015	0.048
AFG	Afghanistan	South Asia	CEM	CEM	1.575	4.350	15.828
AFG	Afghanistan	South Asia	CREM	CREM	0.047	0.199	0.696
AFG	Afghanistan	South Asia	WASOTH	WASOTH	24.029	101.326	358.984
AFG	Afghanistan	South Asia	WI	WI	0.075	0.315	1.116
AGO	Angola	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
AGO	Angola	Sub-Saharan Africa	CEM	CEM	49.613	137.025	498.566
AGO	Angola	Sub-Saharan Africa	CREM	CREM	0.643	2.572	9.002
AGO	Angola	Sub-Saharan Africa	CSP	CSP-C	70.000	200.000	390.000
AGO	Angola	Sub-Saharan Africa	OR	CO-OR	0.583	1.296	2.138
AGO	Angola	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.126	0.280	0.462
AGO	Angola	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	1.484	3.298	5.442
AGO	Angola	Sub-Saharan Africa	SC-IND-gas	NG-IND	0.059	0.131	0.216
AGO	Angola	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.918	2.040	3.366
AGO	Angola	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.220	0.488	0.805
AGO	Angola	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	1.485	3.300	5.445
AGO	Angola	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.137	0.304	0.502
AGO	Angola	Sub-Saharan Africa	WASOTH	WASOTH	66.027	267.937	889.932
AGO	Angola	Sub-Saharan Africa	WI	WI	0.205	0.833	2.765
AIA	Anguilla	Central America and the Caribbean	CREM	CREM	0.002	0.010	0.032
AIA	Anguilla	Central America and the Caribbean	WASOTH	WASOTH	0.095	0.366	1.206
AIA	Anguilla	Central America and the Caribbean	WI	WI	0.000	0.001	0.004
ALB	Albania	CIS & other European countries	CEM	CEM	20.396	56.333	204.966
ALB	Albania	CIS & other European countries	CREM	CREM	0.325	1.083	3.574
ALB	Albania	CIS & other European countries	OR	CO-OR	0.488	1.085	1.790
ALB	Albania	CIS & other European countries	SC-DR-gas	NG-DR	0.000	0.000	0.000
ALB	Albania	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.045	0.100	0.165
ALB	Albania	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.380	0.844	1.393
ALB	Albania	CIS & other European countries	SC-IND-coal	BC-IND	24.140	38.318	54.794
ALB	Albania	CIS & other European countries	SC-IND-gas	NG-IND	0.000	0.000	0.000
ALB	Albania	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.072	0.160	0.264
ALB	Albania	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.015	0.034	0.056
ALB	Albania	CIS & other European countries	SC-PP-coal	BC-L-PP	0.062	0.098	0.140
ALB	Albania	CIS & other European countries	SC-PP-gas	NG-PP	0.001	0.001	0.002
ALB	Albania	CIS & other European countries	SC-PP-oil	CO-HF-PP	0.081	0.180	0.297
ALB	Albania	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.009	0.020	0.033
ALB	Albania	CIS & other European countries	WASOTH	WASOTH	13.220	51.118	174.505
ALB	Albania	CIS & other European countries	WI	WI	0.041	0.159	0.542
AND	Andorra	CIS & other European countries	CREM	CREM	0.426	1.418	4.681
AND	Andorra	CIS & other European countries	WASOTH	WASOTH	1.001	3.870	13.212
AND	Andorra	CIS & other European countries	WI	WI	0.029	0.111	0.381
ANT	Netherlands Antilles	Central America and the Caribbean	CREM	CREM	0.013	0.051	0.171
ANT	Antigua	Central America and the Caribbean	CREM	CREM	0.015	0.060	0.201
ANT	Netherlands Antilles	Central America and the Caribbean	OR	CO-OR	4.277	9.505	15.683
ANT	Netherlands Antilles	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.273	0.606	1.000
ANT	Netherlands Antilles	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	1.214	2.698	4.452
ANT	Netherlands Antilles	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	4.557	10.127	16.710
ANT	Netherlands Antilles	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.015	0.034	0.056

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
ANT	Antigua	Central America and the Caribbean	WASOTH	WASOTH	0.790	3.039	10.028
ANT	Antigua	Central America and the Caribbean	WI	WI	0.002	0.009	0.031
ARE	United Arab Emirates	Middle Eastern States	CEM	CEM	341.712	943.776	3433.934
ARE	United Arab Emirates	Middle Eastern States	CREM	CREM	0.879	3.908	13.921
ARE	United Arab Emirates	Middle Eastern States	CSP	CSP-C	7.875	22.500	43.875
ARE	United Arab Emirates	Middle Eastern States	NFMP-AL	AL-P	6.125	17.500	34.125
ARE	United Arab Emirates	Middle Eastern States	OR	CO-OR	1.419	3.154	5.203
ARE	United Arab Emirates	Middle Eastern States	SC-DR-oil	CO-LF-DR	3.785	8.410	13.877
ARE	United Arab Emirates	Middle Eastern States	SC-IND-gas	NG-IND	2.597	5.772	9.524
ARE	United Arab Emirates	Middle Eastern States	SC-IND-oil	CO-HF-IND	9.986	22.192	36.617
ARE	United Arab Emirates	Middle Eastern States	SC-PP-gas	NG-PP	2.546	5.658	9.336
ARE	United Arab Emirates	Middle Eastern States	SC-PP-oil	CO-HF-PP	0.348	0.774	1.277
ARE	United Arab Emirates	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.403	0.895	1.476
ARE	United Arab Emirates	Middle Eastern States	WASOTH	WASOTH	86.802	345.343	1148.032
ARE	United Arab Emirates	Middle Eastern States	WI	WI	2.501	9.949	33.074
ARG	Argentina	South America	CEM	CEM	252.000	696.000	2532.400
ARG	Argentina	South America	CREM	CREM	8.909	33.794	116.743
ARG	Argentina	South America	CSP	CSP-P	369.075	777.000	1282.050
ARG	Argentina	South America	NFMP-AL	AL-P	3.631	10.375	20.231
ARG	Argentina	South America	NFMP-AU	GP-L	13.028	1861.200	4839.120
ARG	Argentina	South America	NFMP-PB	PB-P	5.894	16.679	34.744
ARG	Argentina	South America	NFMP-ZN	ZN-P	129.548	344.900	847.529
ARG	Argentina	South America	OR	CO-OR	48.955	103.063	170.055
ARG	Argentina	South America	PISP	PIP	46.526	110.775	792.041
ARG	Argentina	South America	SC-DR-gas	NG-DR	1.127	2.503	4.131
ARG	Argentina	South America	SC-DR-oil	CO-HF-DR	0.477	1.060	1.749
ARG	Argentina	South America	SC-DR-oil	CO-LF-DR	7.937	17.638	29.103
ARG	Argentina	South America	SC-IND-gas	NG-IND	0.653	1.450	2.393
ARG	Argentina	South America	SC-IND-oil	CO-HF-IND	0.539	1.197	1.975
ARG	Argentina	South America	SC-IND-oil	CO-LF-IND	0.050	0.112	0.185
ARG	Argentina	South America	SC-PP-coal	HC-B-PP	44.273	66.576	95.203
ARG	Argentina	South America	SC-PP-gas	NG-PP	1.959	4.354	7.184
ARG	Argentina	South America	SC-PP-oil	CO-HF-PP	23.359	51.908	85.648
ARG	Argentina	South America	SC-PP-oil	CO-LF-PP	0.704	1.564	2.580
ARG	Argentina	South America	SC-PP-oil	CO-PP	0.004	0.010	0.016
ARG	Argentina	South America	WASOTH	WASOTH	245.314	944.601	3214.462
ARG	Argentina	South America	WI	WI	1.668	6.424	21.862
ARM	Armenia	CIS & other European countries	CEM	CEM	20.672	57.094	207.736
ARM	Armenia	CIS & other European countries	CREM	CREM	0.064	0.212	0.701
ARM	Armenia	CIS & other European countries	NFMP-AU	GP-L	0.327	46.728	121.493
ARM	Armenia	CIS & other European countries	NFMP-CU	CU-P	31.396	88.057	440.777
ARM	Armenia	CIS & other European countries	SC-DR-gas	NG-DR	0.076	0.169	0.278
ARM	Armenia	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.009	0.020	0.033
ARM	Armenia	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.106	0.236	0.389
ARM	Armenia	CIS & other European countries	SC-IND-gas	NG-IND	0.043	0.095	0.157
ARM	Armenia	CIS & other European countries	SC-PP-gas	NG-PP	0.029	0.064	0.105
ARM	Armenia	CIS & other European countries	WASOTH	WASOTH	7.747	29.955	102.262
ARM	Armenia	CIS & other European countries	WI	WI	0.024	0.093	0.318
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	CEM	CEM	219.644	598.230	2794.379
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	CREM	CREM	18.504	82.238	308.392
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	NFMP-AL	AL-P	121.464	308.480	639.132
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	NFMP-AU	GP-L	85.470	12210.000	31746.000
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	NFMP-CU	CU-P	289.787	812.772	4068.418

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	NFMP-PB	PB-P	44.625	127.500	248.625
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	NFMP-ZN	ZN-P	1845.769	3102.750	3427.856
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	OR	CO-OR	28.197	59.363	97.948
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	PISP	PIP	6.621	15.133	28.806
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-DR-coal	BC-DR	3.714	5.585	7.986
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-DR-coal	HC-DR	0.950	1.428	2.042
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-DR-gas	NG-DR	0.490	1.032	1.703
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-DR-oil	CO-HF-DR	1.406	2.960	4.884
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-DR-oil	CO-LF-DR	11.261	23.708	39.118
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-coal	BC-IND	88.646	133.303	190.623
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-coal	HC-IND	29.080	43.730	62.534
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-gas	NG-IND	0.897	1.887	3.114
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-oil	CO-HF-IND	7.987	16.815	27.745
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-oil	CO-IND	0.167	0.352	0.580
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-IND-oil	CO-LF-IND	2.286	4.813	7.941
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-coal	BC-L-PP	1352.161	2033.324	2907.654
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-coal	BC-S-PP	350.265	526.714	753.201
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-coal	HC-B-PP	404.291	607.956	869.377
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-gas	NG-PP	1.422	2.994	4.941
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-oil	CO-HF-PP	1.625	3.420	5.643
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-oil	CO-LF-PP	1.145	2.410	3.977
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	SC-PP-oil	CO-PP	0.453	0.954	1.574
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	WASOTH	WASOTH	106.693	380.576	1291.323
AUS	Australia (and Christmas Is.)	Australia, New Zealand & Oceania	WI	WI	70.800	236.000	708.000
AUT	Austria	EU27	CEM	CEM	170.874	469.701	3683.223
AUT	Austria	EU27	CREM	CREM	1.286	4.764	15.721
AUT	Austria	EU27	OR	CO-OR	13.414	28.240	46.597
AUT	Austria	EU27	PISP	PIP	60.555	144.179	1030.877
AUT	Austria	EU27	SC-DR-coal	BC-DR	0.292	0.439	0.627
AUT	Austria	EU27	SC-DR-coal	HC-DR	1.746	2.625	3.754
AUT	Austria	EU27	SC-DR-gas	NG-DR	0.195	0.410	0.677
AUT	Austria	EU27	SC-DR-oil	CO-HF-DR	0.760	1.600	2.640
AUT	Austria	EU27	SC-DR-oil	CO-LF-DR	6.296	13.254	21.869
AUT	Austria	EU27	SC-IND-coal	BC-IND	5.591	8.408	12.023
AUT	Austria	EU27	SC-IND-coal	HC-IND	16.701	25.114	35.913
AUT	Austria	EU27	SC-IND-gas	NG-IND	0.251	0.529	0.872
AUT	Austria	EU27	SC-IND-oil	CO-HF-IND	2.310	4.864	8.026
AUT	Austria	EU27	SC-IND-oil	CO-LF-IND	0.361	0.760	1.254
AUT	Austria	EU27	SC-PP-coal	HC-B-PP	41.503	62.410	89.247
AUT	Austria	EU27	SC-PP-gas	NG-PP	0.319	0.671	1.107
AUT	Austria	EU27	SC-PP-oil	CO-HF-PP	2.539	5.346	8.821
AUT	Austria	EU27	SC-PP-oil	CO-LF-PP	0.009	0.018	0.030
AUT	Austria	EU27	WASOTH	WASOTH	18.299	87.786	340.487
AUT	Austria	EU27	WI	WI	6.641	31.860	123.573
AZE	Azerbaijan	CIS & other European countries	CEM	CEM	35.363	97.668	355.367
AZE	Azerbaijan	CIS & other European countries	CREM	CREM	0.196	0.653	2.154
AZE	Azerbaijan	CIS & other European countries	CSP	CSP-C	1015.000	2900.000	5655.000
AZE	Azerbaijan	CIS & other European countries	NFMP-AL	AL-P	0.525	1.500	2.925
AZE	Azerbaijan	CIS & other European countries	NFMP-AU	GP-L	0.122	17.474	45.431
AZE	Azerbaijan	CIS & other European countries	OR	CO-OR	6.184	13.743	22.676
AZE	Azerbaijan	CIS & other European countries	SC-DR-gas	NG-DR	0.249	0.553	0.913
AZE	Azerbaijan	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.054	0.120	0.198
AZE	Azerbaijan	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.644	1.430	2.360

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
AZE	Azerbaijan	CIS & other European countries	SC-IND-gas	NG-IND	0.029	0.064	0.105
AZE	Azerbaijan	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.702	1.560	2.574
AZE	Azerbaijan	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.023	0.052	0.086
AZE	Azerbaijan	CIS & other European countries	SC-PP-gas	NG-PP	0.471	1.046	1.725
AZE	Azerbaijan	CIS & other European countries	SC-PP-oil	CO-HF-PP	1.476	3.280	5.412
AZE	Azerbaijan	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.012	0.026	0.043
AZE	Azerbaijan	CIS & other European countries	WASOTH	WASOTH	41.783	161.560	551.531
AZE	Azerbaijan	CIS & other European countries	WI	WI	0.130	0.502	1.714
BDI	Burundi	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
BDI	Burundi	Sub-Saharan Africa	CREM	CREM	0.233	0.932	3.261
BDI	Burundi	Sub-Saharan Africa	NFMP-AU	GP-L	0.289	41.250	107.250
BDI	Burundi	Sub-Saharan Africa	WASOTH	WASOTH	1.949	7.908	26.265
BDI	Burundi	Sub-Saharan Africa	WI	WI	0.006	0.025	0.082
BEL	Belgium	EU27	CEM	CEM	245.414	672.310	4619.346
BEL	Belgium	EU27	CREM	CREM	2.591	9.595	31.664
BEL	Belgium	EU27	CSP	CSP-C	216.563	618.750	1206.563
BEL	Belgium	EU27	NFMP-ZN	ZN-P	21.622	57.564	141.453
BEL	Belgium	EU27	OR	CO-OR	50.588	106.502	175.728
BEL	Belgium	EU27	PISP	PIP	50.504	120.247	859.767
BEL	Belgium	EU27	SC-DR-coal	HC-DR	32.294	48.562	69.444
BEL	Belgium	EU27	SC-DR-gas	NG-DR	0.582	1.226	2.023
BEL	Belgium	EU27	SC-DR-oil	CO-HF-DR	1.007	2.120	3.498
BEL	Belgium	EU27	SC-DR-oil	CO-LF-DR	10.309	21.704	35.812
BEL	Belgium	EU27	SC-IND-coal	BC-IND	11.182	16.815	24.045
BEL	Belgium	EU27	SC-IND-coal	HC-IND	13.886	20.882	29.861
BEL	Belgium	EU27	SC-IND-gas	NG-IND	0.441	0.929	1.534
BEL	Belgium	EU27	SC-IND-oil	CO-HF-IND	4.016	8.455	13.951
BEL	Belgium	EU27	SC-IND-oil	CO-LF-IND	0.114	0.239	0.395
BEL	Belgium	EU27	SC-PP-coal	HC-B-PP	59.914	90.097	128.838
BEL	Belgium	EU27	SC-PP-gas	NG-PP	0.552	1.162	1.917
BEL	Belgium	EU27	SC-PP-oil	CO-HF-PP	3.146	6.624	10.930
BEL	Belgium	EU27	SC-PP-oil	CO-LF-PP	0.008	0.016	0.027
BEL	Belgium	EU27	WASOTH	WASOTH	22.316	107.055	415.223
BEL	Belgium	EU27	WI	WI	8.099	38.854	150.698
BEN	Benin	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
BEN	Benin	Sub-Saharan Africa	CEM	CEM	47.250	130.500	474.825
BEN	Benin	Sub-Saharan Africa	CREM	CREM	0.160	0.639	2.235
BEN	Benin	Sub-Saharan Africa	NFMP-AU	GP-L	0.008	1.100	2.860
BEN	Benin	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.320	0.710	1.172
BEN	Benin	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.396	0.880	1.452
BEN	Benin	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.004	0.008	0.013
BEN	Benin	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.026	0.058	0.096
BEN	Benin	Sub-Saharan Africa	WASOTH	WASOTH	7.994	32.441	107.750
BEN	Benin	Sub-Saharan Africa	WI	WI	0.025	0.101	0.335
BFA	Burkina Faso	Sub-Saharan Africa	ASGM	ASGM	18427.500	26325.000	34222.500
BFA	Burkina Faso	Sub-Saharan Africa	CEM	CEM	0.945	2.610	9.497
BFA	Burkina Faso	Sub-Saharan Africa	CREM	CREM	0.494	1.976	6.917
BFA	Burkina Faso	Sub-Saharan Africa	NFMP-AU	GP-L	5.198	742.500	1930.500
BFA	Burkina Faso	Sub-Saharan Africa	WASOTH	WASOTH	11.770	47.761	158.634
BFA	Burkina Faso	Sub-Saharan Africa	WI	WI	0.037	0.148	0.493
BGD	Bangladesh	South Asia	CEM	CEM	157.500	435.000	1582.750
BGD	Bangladesh	South Asia	CREM	CREM	2.571	10.825	37.889
BGD	Bangladesh	South Asia	OR	CO-OR	1.530	3.400	5.610

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
BGD	Bangladesh	South Asia	SC-DR-gas	NG-DR	0.277	0.616	1.016
BGD	Bangladesh	South Asia	SC-DR-oil	CO-LF-DR	2.223	4.940	8.151
BGD	Bangladesh	South Asia	SC-IND-coal	HC-IND	70.875	112.500	160.875
BGD	Bangladesh	South Asia	SC-IND-gas	NG-IND	0.256	0.569	0.938
BGD	Bangladesh	South Asia	SC-IND-oil	CO-HF-IND	1.458	3.240	5.346
BGD	Bangladesh	South Asia	SC-IND-oil	CO-LF-IND	0.068	0.152	0.251
BGD	Bangladesh	South Asia	SC-PP-coal	HC-B-PP	32.390	51.413	73.520
BGD	Bangladesh	South Asia	SC-PP-gas	NG-PP	0.861	1.914	3.158
BGD	Bangladesh	South Asia	SC-PP-oil	CO-HF-PP	2.844	6.320	10.428
BGD	Bangladesh	South Asia	SC-PP-oil	CO-LF-PP	0.329	0.732	1.208
BGD	Bangladesh	South Asia	WASOTH	WASOTH	190.954	805.226	2852.802
BGD	Bangladesh	South Asia	WI	WI	0.593	2.502	8.865
BGR	Bulgaria	EU27	CEM	CEM	73.371	202.645	737.324
BGR	Bulgaria	EU27	CREM	CREM	0.135	0.448	1.480
BGR	Bulgaria	EU27	NFMP-AU	GP-L	1.455	207.900	540.540
BGR	Bulgaria	EU27	NFMP-CU	CU-P	1172.884	3289.608	16466.486
BGR	Bulgaria	EU27	NFMP-PB	PB-P	56.007	157.500	342.069
BGR	Bulgaria	EU27	NFMP-ZN	ZN-T	513.796	1367.898	3361.359
BGR	Bulgaria	EU27	OR	CO-OR	9.558	21.240	35.046
BGR	Bulgaria	EU27	PISP	PIP	8.891	21.168	151.351
BGR	Bulgaria	EU27	SC-DR-coal	BC-DR	12.002	19.050	27.242
BGR	Bulgaria	EU27	SC-DR-coal	HC-DR	18.239	28.950	41.399
BGR	Bulgaria	EU27	SC-DR-gas	NG-DR	0.035	0.077	0.127
BGR	Bulgaria	EU27	SC-DR-oil	CO-HF-DR	0.108	0.240	0.396
BGR	Bulgaria	EU27	SC-DR-oil	CO-LF-DR	1.468	3.262	5.382
BGR	Bulgaria	EU27	SC-IND-coal	BC-IND	1.198	1.901	2.719
BGR	Bulgaria	EU27	SC-IND-coal	HC-IND	21.174	33.609	48.061
BGR	Bulgaria	EU27	SC-IND-gas	NG-IND	0.063	0.140	0.231
BGR	Bulgaria	EU27	SC-IND-oil	CO-HF-IND	0.945	2.100	3.465
BGR	Bulgaria	EU27	SC-IND-oil	CO-LF-IND	0.053	0.118	0.195
BGR	Bulgaria	EU27	SC-PP-coal	BC-L-PP	1507.382	2392.670	3421.518
BGR	Bulgaria	EU27	SC-PP-coal	HC-A-PP	80.018	127.013	181.628
BGR	Bulgaria	EU27	SC-PP-coal	HC-B-PP	96.248	152.775	218.468
BGR	Bulgaria	EU27	SC-PP-gas	NG-PP	0.099	0.221	0.365
BGR	Bulgaria	EU27	SC-PP-oil	CO-HF-PP	1.593	3.540	5.841
BGR	Bulgaria	EU27	SC-PP-oil	CO-LF-PP	0.002	0.004	0.007
BGR	Bulgaria	EU27	WASOTH	WASOTH	22.749	109.132	122.060
BGR	Bulgaria	EU27	WI	WI	0.655	3.144	3.516
BHR	Bahrain	Middle Eastern States	CEM	CEM	17.086	47.189	171.697
BHR	Bahrain	Middle Eastern States	CREM	CREM	0.075	0.331	1.180
BHR	Bahrain	Middle Eastern States	NFMP-AL	AL-P	3.806	10.875	21.206
BHR	Bahrain	Middle Eastern States	OR	CO-OR	2.317	5.149	8.496
BHR	Bahrain	Middle Eastern States	SC-DR-oil	CO-LF-DR	0.389	0.864	1.426
BHR	Bahrain	Middle Eastern States	SC-IND-gas	NG-IND	0.308	0.685	1.131
BHR	Bahrain	Middle Eastern States	SC-PP-gas	NG-PP	0.518	1.151	1.900
BHR	Bahrain	Middle Eastern States	WASOTH	WASOTH	6.645	26.436	87.883
BHR	Bahrain	Middle Eastern States	WI	WI	0.191	0.762	2.532
BHS	Bahamas	Central America and the Caribbean	CREM	CREM	0.054	0.220	0.737
BHS	Bahamas	Central America and the Caribbean	WASOTH	WASOTH	4.682	18.006	59.419
BHS	Bahamas	Central America and the Caribbean	WI	WI	0.015	0.056	0.185
BIH	Bosnia-Herzegovina	CIS & other European countries	CEM	CEM	29.602	81.758	297.478
BIH	Bosnia-Herzegovina	CIS & other European countries	CREM	CREM	0.784	2.613	8.623
BIH	Bosnia-Herzegovina	CIS & other European countries	NFMP-AL	AL-P	14.868	37.760	78.234

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
BIH	Bosnia-Herzegovina	CIS & other European countries	OR	CO-OR	1.496	3.325	5.487
BIH	Bosnia-Herzegovina	CIS & other European countries	PISP	PIP	4.899	11.664	83.398
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-DR-coal	BC-DR	36.666	58.200	83.226
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-DR-gas	NG-DR	0.007	0.014	0.024
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-DR-oil	CO-HF-DR	1.737	3.860	6.369
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.503	1.118	1.845
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-IND-coal	BC-IND	15.111	23.985	34.299
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-IND-gas	NG-IND	0.007	0.015	0.025
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-PP-coal	BC-L-PP	306.354	486.276	695.375
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-PP-coal	BC-S-PP	437.327	694.170	992.663
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-PP-gas	NG-PP	0.006	0.013	0.022
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-PP-oil	CO-HF-PP	0.387	0.860	1.419
BIH	Bosnia-Herzegovina	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.023	0.050	0.083
BIH	Bosnia-Herzegovina	CIS & other European countries	WASOTH	WASOTH	9.979	38.587	131.728
BIH	Bosnia-Herzegovina	CIS & other European countries	WI	WI	0.288	1.112	3.795
BLR	Belarus	CIS & other European countries	CEM	CEM	119.897	323.531	618.516
BLR	Belarus	CIS & other European countries	CREM	CREM	1.006	3.355	11.071
BLR	Belarus	CIS & other European countries	OR	CO-OR	33.100	73.556	121.367
BLR	Belarus	CIS & other European countries	SC-DR-coal	HC-DR	2.079	3.300	4.719
BLR	Belarus	CIS & other European countries	SC-DR-gas	NG-DR	0.187	0.416	0.686
BLR	Belarus	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.423	0.940	1.551
BLR	Belarus	CIS & other European countries	SC-DR-oil	CO-LF-DR	1.840	4.088	6.745
BLR	Belarus	CIS & other European countries	SC-IND-coal	HC-IND	0.992	1.575	2.252
BLR	Belarus	CIS & other European countries	SC-IND-gas	NG-IND	0.171	0.380	0.627
BLR	Belarus	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.477	1.060	1.749
BLR	Belarus	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.056	0.124	0.205
BLR	Belarus	CIS & other European countries	SC-PP-coal	HC-B-PP	2.126	3.375	4.826
BLR	Belarus	CIS & other European countries	SC-PP-gas	NG-PP	1.044	2.320	3.828
BLR	Belarus	CIS & other European countries	SC-PP-oil	CO-HF-PP	23.607	52.460	86.559
BLR	Belarus	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.002	0.004	0.007
BLR	Belarus	CIS & other European countries	WASOTH	WASOTH	40.812	157.806	538.717
BLR	Belarus	CIS & other European countries	WI	WI	1.176	4.546	15.520
BLZ	Belize	Central America and the Caribbean	CREM	CREM	0.052	0.212	0.712
BLZ	Belize	Central America and the Caribbean	NFMP-AU	GP-L	0.001	0.198	0.515
BLZ	Belize	Central America and the Caribbean	WASOTH	WASOTH	1.226	4.717	15.565
BLZ	Belize	Central America and the Caribbean	WI	WI	0.004	0.015	0.048
BMU	Bermuda	Central America and the Caribbean	CREM	CREM	0.012	0.048	0.160
BMU	Bermuda	Central America and the Caribbean	WASOTH	WASOTH	2.439	9.379	30.951
BMU	Bermuda	Central America and the Caribbean	WI	WI	0.008	0.029	0.096
BOL	Bolivia	South America	ASGM	ASGM	31500.000	45000.000	58500.000
BOL	Bolivia	South America	CEM	CEM	57.758	159.523	580.426
BOL	Bolivia	South America	CREM	CREM	2.599	9.858	34.054
BOL	Bolivia	South America	NFMP-AU	GP-L	1.940	277.200	720.720
BOL	Bolivia	South America	NFMP-PB	PB-T	0.123	0.347	0.722
BOL	Bolivia	South America	OR	CO-OR	0.908	2.018	3.330
BOL	Bolivia	South America	SC-DR-gas	NG-DR	0.037	0.083	0.137
BOL	Bolivia	South America	SC-DR-oil	CO-LF-DR	0.860	1.910	3.152
BOL	Bolivia	South America	SC-IND-gas	NG-IND	0.059	0.131	0.216
BOL	Bolivia	South America	SC-IND-oil	CO-HF-IND	0.017	0.038	0.063
BOL	Bolivia	South America	SC-IND-oil	CO-LF-IND	0.043	0.095	0.157
BOL	Bolivia	South America	SC-PP-gas	NG-PP	0.145	0.322	0.532
BOL	Bolivia	South America	SC-PP-oil	CO-LF-PP	0.027	0.059	0.097
BOL	Bolivia	South America	WASOTH	WASOTH	29.762	114.602	389.990

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
BOL	Bolivia	South America	WI	WI	0.092	0.356	1.212
BRA	Brazil	South America	ASGM	ASGM	15750.000	22500.000	29250.000
BRA	Brazil	South America	CEM	CEM	1346.625	1748.250	7432.425
BRA	Brazil	South America	CREM	CREM	5.193	19.698	68.049
BRA	Brazil	South America	CSP	CSP-P	530.575	1117.000	1843.050
BRA	Brazil	South America	NFMP-AL	AL-P	96.768	245.760	509.184
BRA	Brazil	South America	NFMP-AU	GP-L	13.092	1378.080	3031.776
BRA	Brazil	South America	NFMP-CU	CU-P	570.724	1600.720	8012.576
BRA	Brazil	South America	NFMP-ZN	ZN-P	1323.875	3514.750	6895.200
BRA	Brazil	South America	OR	CO-OR	40.703	90.451	149.244
BRA	Brazil	South America	PISP	PIP	1131.864	2610.853	5033.310
BRA	Brazil	South America	SC-DR-gas	NG-DR	0.225	0.500	0.826
BRA	Brazil	South America	SC-DR-oil	CO-HF-DR	11.853	26.340	43.461
BRA	Brazil	South America	SC-DR-oil	CO-LF-DR	30.913	68.696	113.348
BRA	Brazil	South America	SC-IND-coal	BC-IND	62.654	99.450	142.214
BRA	Brazil	South America	SC-IND-coal	HC-IND	239.274	379.800	543.114
BRA	Brazil	South America	SC-IND-gas	NG-IND	0.710	1.577	2.602
BRA	Brazil	South America	SC-IND-oil	CO-HF-IND	32.644	72.542	119.694
BRA	Brazil	South America	SC-IND-oil	CO-LF-IND	0.599	1.330	2.195
BRA	Brazil	South America	SC-PP-coal	BC-L-PP	88.720	140.826	201.381
BRA	Brazil	South America	SC-PP-coal	BC-S-PP	207.267	328.995	470.463
BRA	Brazil	South America	SC-PP-coal	HC-B-PP	5.528	8.775	12.548
BRA	Brazil	South America	SC-PP-gas	NG-PP	0.768	1.708	2.818
BRA	Brazil	South America	SC-PP-oil	CO-HF-PP	19.041	42.313	69.816
BRA	Brazil	South America	SC-PP-oil	CO-LF-PP	1.582	3.515	5.800
BRA	Brazil	South America	WASOTH	WASOTH	828.534	3190.334	10856.658
BRA	Brazil	South America	WI	WI	5.635	21.698	73.838
BRB	Barbados	Central America and the Caribbean	CEM	CEM	13.860	35.040	112.632
BRB	Barbados	Central America and the Caribbean	CREM	CREM	0.046	0.187	0.627
BRB	Barbados	Central America and the Caribbean	WASOTH	WASOTH	2.846	10.944	36.117
BRB	Barbados	Central America and the Caribbean	WI	WI	0.009	0.034	0.112
BRN	Brunei Darussalam	East and Southeast Asia	CEM	CEM	5.544	15.312	55.713
BRN	Brunei Darussalam	East and Southeast Asia	CREM	CREM	0.049	0.175	0.557
BRN	Brunei Darussalam	East and Southeast Asia	OR	CO-OR	0.087	0.193	0.319
BRN	Brunei Darussalam	East and Southeast Asia	SC-DR-gas	NG-DR	0.003	0.006	0.010
BRN	Brunei Darussalam	East and Southeast Asia	SC-DR-oil	CO-LF-DR	0.117	0.260	0.429
BRN	Brunei Darussalam	East and Southeast Asia	SC-IND-gas	NG-IND	0.080	0.177	0.293
BRN	Brunei Darussalam	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.075	0.167	0.276
BRN	Brunei Darussalam	East and Southeast Asia	SC-PP-gas	NG-PP	0.191	0.424	0.700
BRN	Brunei Darussalam	East and Southeast Asia	SC-PP-oil	CO-HF-PP	0.718	1.596	2.633
BRN	Brunei Darussalam	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.008	0.017	0.028
BRN	Brunei Darussalam	East and Southeast Asia	WASOTH	WASOTH	10.839	42.905	147.861
BRN	Brunei Darussalam	East and Southeast Asia	WI	WI	0.312	1.236	4.260
BTN	Bhutan	South Asia	CEM	CEM	5.670	15.660	56.979
BTN	Bhutan	South Asia	CREM	CREM	0.100	0.422	1.476
BTN	Bhutan	South Asia	WASOTH	WASOTH	2.972	12.534	44.405
BTN	Bhutan	South Asia	WI	WI	0.009	0.039	0.138
BWA	Botswana	Sub-Saharan Africa	ASGM	ASGM	100.000	400.000	700.000
BWA	Botswana	Sub-Saharan Africa	CREM	CREM	0.069	0.278	0.973
BWA	Botswana	Sub-Saharan Africa	NFMP-AU	GP-L	0.693	99.000	257.400
BWA	Botswana	Sub-Saharan Africa	NFMP-CU	CU-P	111.621	313.065	1567.080
BWA	Botswana	Sub-Saharan Africa	SC-DR-coal	HC-DR	1.418	2.250	3.218
BWA	Botswana	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.253	0.562	0.927

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
BWA	Botswana	Sub-Saharan Africa	SC-IND-coal	HC-IND	24.641	39.113	55.931
BWA	Botswana	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.081	0.180	0.297
BWA	Botswana	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.107	0.238	0.393
BWA	Botswana	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	27.145	43.088	61.615
BWA	Botswana	Sub-Saharan Africa	WASOTH	WASOTH	15.863	64.372	213.807
BWA	Botswana	Sub-Saharan Africa	WI	WI	0.049	0.200	0.664
CAF	Central African Republic	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
CAF	Central African Republic	Sub-Saharan Africa	CREM	CREM	0.121	0.484	1.694
CAF	Central African Republic	Sub-Saharan Africa	NFMP-AU	GP-L	0.004	0.550	1.430
CAF	Central African Republic	Sub-Saharan Africa	WASOTH	WASOTH	1.976	8.017	26.628
CAF	Central African Republic	Sub-Saharan Africa	WI	WI	0.006	0.025	0.083
CAN	Canada	North America	CEM	CEM	152.252	420.506	1530.013
CAN	Canada	North America	CREM	CREM	24.884	90.975	305.033
CAN	Canada	North America	NFMP-AL	AL-P	12.963	37.038	72.223
CAN	Canada	North America	NFMP-AU	GP-L	1.874	267.759	696.174
CAN	Canada	North America	NFMP-CU	CU-P	25.922	46.717	91.468
CAN	Canada	North America	NFMP-PB	PB-P	6.777	12.422	19.473
CAN	Canada	North America	NFMP-ZN	ZN-P	192.613	315.880	2801.525
CAN	Canada	North America	OR	CO-OR	61.411	129.286	213.321
CAN	Canada	North America	PISP	PIP	82.586	196.633	1405.925
CAN	Canada	North America	SC-DR-coal	BC-DR	7.878	11.846	16.940
CAN	Canada	North America	SC-DR-oil	CO-HF-DR	20.406	42.960	70.884
CAN	Canada	North America	SC-DR-oil	CO-LF-DR	21.689	45.662	75.342
CAN	Canada	North America	SC-IND-coal	HC-IND	84.011	126.332	180.655
CAN	Canada	North America	SC-IND-oil	CO-HF-IND	9.260	19.494	32.165
CAN	Canada	North America	SC-IND-oil	CO-LF-IND	2.111	4.444	7.333
CAN	Canada	North America	SC-PP-coal	BC-L-PP	391.488	588.704	841.847
CAN	Canada	North America	SC-PP-coal	BC-S-PP	973.453	1463.839	2093.290
CAN	Canada	North America	SC-PP-coal	HC-B-PP	61.758	92.869	132.803
CAN	Canada	North America	SC-PP-gas	NG-PP	2.525	5.316	8.772
CAN	Canada	North America	SC-PP-oil	CO-HF-PP	14.569	30.672	50.609
CAN	Canada	North America	SC-PP-oil	CO-LF-PP	0.085	0.178	0.294
CAN	Canada	North America	WASOTH	WASOTH	91.541	381.954	1376.313
CAN	Canada	North America	WI	WI	33.223	138.623	499.508
CCK	Cocos Islands	Australia, New Zealand & Oceania	CREM	CREM	0.000	0.001	0.003
CHE	Switzerland	CIS & other European countries	CEM	CEM	127.460	299.788	2756.842
CHE	Switzerland	CIS & other European countries	CREM	CREM	0.580	1.934	6.381
CHE	Switzerland	CIS & other European countries	CSP	CSP-C	11.813	33.750	65.813
CHE	Switzerland	CIS & other European countries	OR	CO-OR	7.668	16.143	26.636
CHE	Switzerland	CIS & other European countries	PISP	PIP	1.077	2.565	18.340
CHE	Switzerland	CIS & other European countries	SC-DR-coal	HC-DR	1.222	1.838	2.628
CHE	Switzerland	CIS & other European countries	SC-DR-gas	NG-DR	0.183	0.385	0.636
CHE	Switzerland	CIS & other European countries	SC-DR-oil	CO-LF-DR	5.552	11.688	19.285
CHE	Switzerland	CIS & other European countries	SC-IND-coal	BC-IND	4.855	7.301	10.441
CHE	Switzerland	CIS & other European countries	SC-IND-coal	HC-IND	6.505	9.782	13.988
CHE	Switzerland	CIS & other European countries	SC-IND-gas	NG-IND	0.090	0.190	0.314
CHE	Switzerland	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.596	1.254	2.069
CHE	Switzerland	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.568	1.195	1.972
CHE	Switzerland	CIS & other European countries	SC-PP-gas	NG-PP	0.023	0.048	0.080
CHE	Switzerland	CIS & other European countries	SC-PP-oil	CO-HF-PP	0.180	0.378	0.624
CHE	Switzerland	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.016	0.034	0.056
CHE	Switzerland	CIS & other European countries	WASOTH	WASOTH	27.558	106.558	363.767
CHE	Switzerland	CIS & other European countries	WI	WI	10.002	38.673	132.023

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
CHL	Chile	South America	ASGM	ASGM	500.000	2000.000	3500.000
CHL	Chile	South America	CEM	CEM	97.675	269.770	981.558
CHL	Chile	South America	CREM	CREM	4.530	17.182	59.356
CHL	Chile	South America	NFMP-AU	GP-L	11.319	1617.026	4204.269
CHL	Chile	South America	NFMP-CU	CU-P	4936.438	13845.319	69304.230
CHL	Chile	South America	OR	CO-OR	4.773	10.049	16.581
CHL	Chile	South America	PISP	PIP	111.820	291.703	550.763
CHL	Chile	South America	SC-DR-coal	HC-DR	1.496	2.250	3.218
CHL	Chile	South America	SC-DR-gas	NG-DR	0.058	0.122	0.202
CHL	Chile	South America	SC-DR-oil	CO-HF-DR	3.154	6.640	10.956
CHL	Chile	South America	SC-DR-oil	CO-LF-DR	3.544	7.460	12.309
CHL	Chile	South America	SC-IND-coal	HC-IND	13.915	20.925	29.923
CHL	Chile	South America	SC-IND-gas	NG-IND	0.017	0.035	0.058
CHL	Chile	South America	SC-IND-oil	CO-HF-IND	5.749	12.103	19.970
CHL	Chile	South America	SC-IND-oil	CO-LF-IND	1.770	3.726	6.148
CHL	Chile	South America	SC-PP-coal	HC-B-PP	393.820	592.211	846.862
CHL	Chile	South America	SC-PP-gas	NG-PP	0.084	0.176	0.291
CHL	Chile	South America	SC-PP-oil	CO-HF-PP	2.455	5.168	8.527
CHL	Chile	South America	SC-PP-oil	CO-LF-PP	1.693	3.564	5.881
CHL	Chile	South America	WASOTH	WASOTH	167.546	645.147	2195.425
CHL	Chile	South America	WI	WI	0.521	2.005	6.822
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	ASGM	ASGM	83343.750	166687.500	250031.250
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	CEM	CEM	31472.280	85033.800	302407.560
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	CREM	CREM	220.426	794.006	2524.228
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	CSP	CSP-C	141.750	405.000	789.750
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-AL	AL-P	771.120	1944.000	3664.440
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-AU	GP-L	88.704	12672.000	32947.200
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-CU	CU-P	8600.364	24121.599	120743.254
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-HG	HG-P	5512.500	9450.000	14332.500
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-PB	PB-P	1164.838	3296.463	6866.927
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	NFMP-ZN	ZN-T	24689.541	43305.615	67436.844
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	OR	CO-OR	567.774	1261.720	2081.837
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	PISP	PIP	9574.812	22797.170	162999.767
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-DR-coal	HC-DR	17579.142	27903.400	39901.862
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-DR-gas	NG-DR	2.688	5.974	9.856
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-DR-oil	CO-DR	0.774	1.720	2.838
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-DR-oil	CO-HF-DR	34.236	76.080	125.532
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-DR-oil	CO-LF-DR	98.902	219.782	362.640
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-IND-coal	HC-IND	34619.514	54951.610	78580.802
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-IND-gas	NG-IND	1.669	3.709	6.120
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-IND-oil	CO-HF-IND	80.267	178.372	294.314

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-IND-oil	CO-IND	9.807	21.793	35.958
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-IND-oil	CO-LF-IND	17.573	39.051	64.434
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-PP-coal	HC-B-PP	60922.102	96701.749	138283.502
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-PP-gas	NG-PP	2.385	5.300	8.745
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-PP-oil	CO-HF-PP	54.934	122.075	201.424
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-PP-oil	CO-LF-PP	5.670	12.599	20.788
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	SC-PP-oil	CO-PP	21.089	46.864	77.325
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	WASOTH	WASOTH	5683.701	22497.984	77533.098
CHN	China (and Hong Kong if not separately identified)	East and Southeast Asia	WI	WI	163.745	648.158	2233.699
CIV	Ivory Coast	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
CIV	Ivory Coast	Sub-Saharan Africa	CEM	CEM	20.475	56.550	205.758
CIV	Ivory Coast	Sub-Saharan Africa	CREM	CREM	0.150	0.598	2.093
CIV	Ivory Coast	Sub-Saharan Africa	NFMP-AU	GP-L	2.531	361.515	939.939
CIV	Ivory Coast	Sub-Saharan Africa	OR	CO-OR	1.011	2.246	3.705
CIV	Ivory Coast	Sub-Saharan Africa	SC-DR-gas	NG-DR	0.025	0.055	0.091
CIV	Ivory Coast	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.072	0.160	0.264
CIV	Ivory Coast	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.368	0.818	1.350
CIV	Ivory Coast	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.171	0.380	0.627
CIV	Ivory Coast	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.093	0.206	0.340
CIV	Ivory Coast	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.114	0.252	0.416
CIV	Ivory Coast	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	0.162	0.360	0.594
CIV	Ivory Coast	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.002	0.004	0.007
CIV	Ivory Coast	Sub-Saharan Africa	WASOTH	WASOTH	21.331	86.562	287.510
CIV	Ivory Coast	Sub-Saharan Africa	WI	WI	0.066	0.269	0.893
CMR	Cameroon	Sub-Saharan Africa	ASGM	ASGM	281.250	1125.000	1968.750
CMR	Cameroon	Sub-Saharan Africa	CEM	CEM	31.500	87.000	316.550
CMR	Cameroon	Sub-Saharan Africa	CREM	CREM	0.399	1.597	5.591
CMR	Cameroon	Sub-Saharan Africa	NFMP-AL	AL-P	6.384	9.880	13.338
CMR	Cameroon	Sub-Saharan Africa	NFMP-AU	GP-L	0.616	88.000	228.800
CMR	Cameroon	Sub-Saharan Africa	OR	CO-OR	0.555	1.233	2.035
CMR	Cameroon	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.389	0.864	1.426
CMR	Cameroon	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.783	1.740	2.871
CMR	Cameroon	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.009	0.020	0.033
CMR	Cameroon	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.022	0.048	0.079
CMR	Cameroon	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	0.684	1.520	2.508
CMR	Cameroon	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.212	0.472	0.779
CMR	Cameroon	Sub-Saharan Africa	WASOTH	WASOTH	25.440	103.236	342.892
CMR	Cameroon	Sub-Saharan Africa	WI	WI	0.079	0.321	1.066
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	ASGM	ASGM	2812.500	11250.000	19687.500
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	CEM	CEM	13.986	38.628	140.548
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	CREM	CREM	1.970	7.882	27.586
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	NFMP-AU	GP-L	0.770	110.000	286.000
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.253	0.562	0.927
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	SC-IND-coal	HC-IND	17.187	27.281	39.012
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.378	0.840	1.386
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.001	0.002	0.003
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.002	0.004	0.007
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	WASOTH	WASOTH	13.034	52.893	175.681

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
COD	Dem. Rep. of Congo (Zaire)	Sub-Saharan Africa	WI	WI	0.041	0.164	0.546
COG	Congo	Sub-Saharan Africa	ASGM	ASGM	281.250	1125.000	1968.750
COG	Congo	Sub-Saharan Africa	CEM	CEM	3.150	8.700	31.655
COG	Congo	Sub-Saharan Africa	CREM	CREM	0.132	0.528	1.847
COG	Congo	Sub-Saharan Africa	NFMP-AU	GP-L	0.039	5.500	14.300
COG	Congo	Sub-Saharan Africa	OR	CO-OR	0.209	0.466	0.768
COG	Congo	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.240	0.534	0.881
COG	Congo	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.162	0.360	0.594
COG	Congo	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.005	0.011	0.018
COG	Congo	Sub-Saharan Africa	WASOTH	WASOTH	9.767	39.634	131.643
COG	Congo	Sub-Saharan Africa	WI	WI	0.030	0.123	0.409
COK	Cook Islands	Australia, New Zealand & Oceania	CREM	CREM	0.019	0.086	0.323
COK	Cook Islands	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.103	0.372	1.286
COK	Cook Islands	Australia, New Zealand & Oceania	WI	WI	0.000	0.001	0.004
COL	Columbia	South America	ASGM	ASGM	30000.000	60000.000	90000.000
COL	Columbia	South America	CEM	CEM	252.000	696.000	2532.400
COL	Columbia	South America	CREM	CREM	10.297	39.058	134.926
COL	Columbia	South America	CSP	CSP-C	38.500	110.000	214.500
COL	Columbia	South America	NFMP-AU	GP-L	13.260	1894.345	4925.298
COL	Columbia	South America	OR	CO-OR	6.552	14.560	24.024
COL	Columbia	South America	PISP	PIP	6.009	14.306	102.290
COL	Columbia	South America	SC-DR-coal	HC-DR	11.907	18.900	27.027
COL	Columbia	South America	SC-DR-gas	NG-DR	0.168	0.374	0.618
COL	Columbia	South America	SC-DR-oil	CO-DR	0.018	0.040	0.066
COL	Columbia	South America	SC-DR-oil	CO-LF-DR	3.857	8.570	14.141
COL	Columbia	South America	SC-IND-coal	HC-IND	166.485	264.263	377.895
COL	Columbia	South America	SC-IND-gas	NG-IND	0.182	0.405	0.668
COL	Columbia	South America	SC-IND-oil	CO-HF-IND	0.205	0.456	0.752
COL	Columbia	South America	SC-IND-oil	CO-IND	0.462	1.026	1.693
COL	Columbia	South America	SC-IND-oil	CO-LF-IND	0.132	0.293	0.483
COL	Columbia	South America	SC-PP-coal	HC-B-PP	111.692	177.289	253.523
COL	Columbia	South America	SC-PP-gas	NG-PP	0.429	0.952	1.571
COL	Columbia	South America	SC-PP-oil	CO-HF-PP	1.094	2.432	4.013
COL	Columbia	South America	SC-PP-oil	CO-LF-PP	0.054	0.120	0.198
COL	Columbia	South America	SC-PP-oil	CO-PP	1.039	2.309	3.809
COL	Colombia	South America	WASOTH	WASOTH	166.070	639.466	2176.095
COL	Colombia	South America	WI	WI	1.129	4.349	14.800
COM	Comoros	Sub-Saharan Africa	CREM	CREM	0.001	0.002	0.007
COM	Comoros	Sub-Saharan Africa	WASOTH	WASOTH	0.459	1.861	6.182
COM	Comoros	Sub-Saharan Africa	WI	WI	0.001	0.006	0.019
CPV	Cape Verde	Sub-Saharan Africa	CREM	CREM	0.015	0.059	0.207
CPV	Cape Verde	Sub-Saharan Africa	WASOTH	WASOTH	1.124	4.562	15.153
CPV	Cape Verde	Sub-Saharan Africa	WI	WI	0.003	0.014	0.047
CRI	Costa Rica	Central America and the Caribbean	ASGM	ASGM	37.500	150.000	262.500
CRI	Costa Rica	Central America and the Caribbean	CEM	CEM	63.000	174.000	633.100
CRI	Costa Rica	Central America and the Caribbean	CREM	CREM	0.789	3.193	10.707
CRI	Costa Rica	Central America and the Caribbean	NFMP-AU	GP-L	0.139	19.800	51.480
CRI	Costa Rica	Central America and the Caribbean	OR	CO-OR	0.169	0.376	0.620
CRI	Costa Rica	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.072	0.160	0.264
CRI	Costa Rica	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.716	1.592	2.627
CRI	Costa Rica	Central America and the Caribbean	SC-IND-coal	HC-IND	0.284	0.450	0.644
CRI	Costa Rica	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	1.009	2.242	3.699
CRI	Costa Rica	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.058	0.129	0.213

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
CRI	Costa Rica	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	0.325	0.722	1.191
CRI	Costa Rica	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.086	0.190	0.314
CRI	Costa Rica	Central America and the Caribbean	WASOTH	WASOTH	28.659	110.226	363.745
CRI	Costa Rica	Central America and the Caribbean	WI	WI	0.089	0.343	1.130
CUB	Cuba	Central America and the Caribbean	CEM	CEM	42.840	118.320	430.508
CUB	Cuba	Central America and the Caribbean	CREM	CREM	1.060	4.291	14.388
CUB	Cuba	Central America and the Caribbean	CSP	CSP-C	12.250	35.000	68.250
CUB	Cuba	Central America and the Caribbean	OR	CO-OR	2.357	5.237	8.641
CUB	Cuba	Central America and the Caribbean	SC-DR-gas	NG-DR	0.012	0.027	0.044
CUB	Cuba	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.549	1.220	2.013
CUB	Cuba	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.576	1.280	2.112
CUB	Cuba	Central America and the Caribbean	SC-IND-coal	HC-IND	1.205	1.913	2.735
CUB	Cuba	Central America and the Caribbean	SC-IND-gas	NG-IND	0.025	0.055	0.091
CUB	Cuba	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	8.807	19.570	32.291
CUB	Cuba	Central America and the Caribbean	SC-IND-oil	CO-IND	5.810	12.911	21.302
CUB	Cuba	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.330	0.733	1.210
CUB	Cuba	Central America and the Caribbean	SC-PP-gas	NG-PP	0.054	0.119	0.196
CUB	Cuba	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	8.730	19.399	32.008
CUB	Cuba	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.289	0.642	1.060
CUB	Cuba	Central America and the Caribbean	SC-PP-oil	CO-PP	11.299	25.109	41.429
CUB	Cuba	Central America and the Caribbean	WASOTH	WASOTH	61.831	237.813	784.783
CUB	Cuba	Central America and the Caribbean	WI	WI	0.192	0.739	2.439
CYM	Cayman Islands	Central America and the Caribbean	CREM	CREM	0.008	0.033	0.111
CYM	Cayman Islands	Central America and the Caribbean	WASOTH	WASOTH	1.219	4.690	15.476
CYM	Cayman Islands	Central America and the Caribbean	WI	WI	0.004	0.015	0.048
CYP	Cyprus	EU27	CEM	CEM	62.790	172.076	536.244
CYP	Cyprus	EU27	CREM	CREM	0.142	0.525	1.731
CYP	Cyprus	EU27	SC-DR-coal	BC-DR	0.092	0.146	0.209
CYP	Cyprus	EU27	SC-DR-oil	CO-HF-DR	0.018	0.040	0.066
CYP	Cyprus	EU27	SC-DR-oil	CO-LF-DR	0.407	0.904	1.492
CYP	Cyprus	EU27	SC-IND-coal	HC-IND	0.918	1.457	2.083
CYP	Cyprus	EU27	SC-IND-oil	CO-HF-IND	0.470	1.045	1.724
CYP	Cyprus	EU27	SC-IND-oil	CO-LF-IND	0.015	0.034	0.056
CYP	Cyprus	EU27	SC-PP-oil	CO-HF-PP	9.526	21.168	34.927
CYP	Cyprus	EU27	SC-PP-oil	CO-LF-PP	0.075	0.166	0.273
CYP	Cyprus	EU27	WASOTH	WASOTH	1.341	6.434	24.953
CYP	Cyprus	EU27	WI	WI	0.487	2.335	9.056
CZE	Czech Republic	EU27	CEM	CEM	98.605	270.753	1790.810
CZE	Czech Republic	EU27	CREM	CREM	4.313	15.976	52.720
CZE	Czech Republic	EU27	CSP	CSP-C	171.742	490.690	956.846
CZE	Czech Republic	EU27	OR	CO-OR	11.912	25.078	41.379
CZE	Czech Republic	EU27	PISP	PIP	42.952	102.267	731.206
CZE	Czech Republic	EU27	SC-DR-coal	BC-DR	115.443	173.599	248.246
CZE	Czech Republic	EU27	SC-DR-coal	HC-DR	6.808	10.238	14.640
CZE	Czech Republic	EU27	SC-DR-gas	NG-DR	0.385	0.811	1.337
CZE	Czech Republic	EU27	SC-DR-oil	CO-HF-DR	0.067	0.140	0.231
CZE	Czech Republic	EU27	SC-DR-oil	CO-LF-DR	3.692	7.772	12.824
CZE	Czech Republic	EU27	SC-IND-coal	BC-IND	209.368	314.839	450.219
CZE	Czech Republic	EU27	SC-IND-coal	HC-IND	44.058	66.253	94.742
CZE	Czech Republic	EU27	SC-IND-gas	NG-IND	0.212	0.447	0.737
CZE	Czech Republic	EU27	SC-IND-oil	CO-HF-IND	1.264	2.660	4.389
CZE	Czech Republic	EU27	SC-IND-oil	CO-LF-IND	0.086	0.181	0.298
CZE	Czech Republic	EU27	SC-PP-coal	BC-L-PP	2083.171	3132.587	4479.600

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CZE	Czech Republic	EU27	SC-PP-coal	HC-B-PP	121.825	183.195	261.969
CZE	Czech Republic	EU27	SC-PP-gas	NG-PP	0.118	0.249	0.411
CZE	Czech Republic	EU27	SC-PP-oil	CO-HF-PP	1.445	3.042	5.019
CZE	Czech Republic	EU27	SC-PP-oil	CO-LF-PP	0.016	0.034	0.056
CZE	Czech Republic	EU27	WASOTH	WASOTH	14.517	69.643	270.118
CZE	Czech Republic	EU27	WI	WI	5.269	25.276	98.034
DEU	Germany	EU27	CEM	CEM	959.286	2618.322	10271.171
DEU	Germany	EU27	CREM	CREM	19.640	72.742	240.050
DEU	Germany	EU27	CSP	CSP-C	384.346	1098.130	2141.354
DEU	Germany	EU27	NFMP-AL	AL-P	1.724	4.925	9.604
DEU	Germany	EU27	NFMP-CU	CU-P	172.430	483.619	2420.805
DEU	Germany	EU27	NFMP-PB	PB-P	8.261	23.603	46.025
DEU	Germany	EU27	NFMP-ZN	ZN-T	277.603	764.786	1269.718
DEU	Germany	EU27	OR	CO-OR	162.958	343.070	566.066
DEU	Germany	EU27	PISP	PIP	307.677	732.564	5237.833
DEU	Germany	EU27	SC-DR-coal	HC-DR	89.725	134.925	192.943
DEU	Germany	EU27	SC-DR-gas	NG-DR	4.461	9.391	15.495
DEU	Germany	EU27	SC-DR-oil	CO-LF-DR	44.404	93.482	154.245
DEU	Germany	EU27	SC-IND-coal	BC-IND	25.748	38.719	55.368
DEU	Germany	EU27	SC-IND-coal	HC-IND	110.030	165.459	236.607
DEU	Germany	EU27	SC-IND-gas	NG-IND	1.675	3.527	5.819
DEU	Germany	EU27	SC-IND-oil	CO-HF-IND	7.428	15.637	25.801
DEU	Germany	EU27	SC-IND-oil	CO-LF-IND	1.463	3.080	5.082
DEU	Germany	EU27	SC-PP-coal	BC-L-PP	5506.018	8279.726	11840.008
DEU	Germany	EU27	SC-PP-coal	HC-A-PP	105.695	158.940	227.284
DEU	Germany	EU27	SC-PP-coal	HC-B-PP	1039.261	1562.798	2234.801
DEU	Germany	EU27	SC-PP-gas	NG-PP	1.914	4.030	6.650
DEU	Germany	EU27	SC-PP-oil	CO-HF-PP	15.210	32.022	52.836
DEU	Germany	EU27	SC-PP-oil	CO-LF-PP	0.423	0.891	1.470
DEU	Germany	EU27	WASOTH	WASOTH	166.076	796.707	3090.099
DEU	Germany	EU27	WI	WI	60.274	289.150	1121.495
DJI	Djibouti	Sub-Saharan Africa	CREM	CREM	0.030	0.119	0.416
DJI	Djibouti	Sub-Saharan Africa	WASOTH	WASOTH	1.144	4.641	15.416
DJI	Djibouti	Sub-Saharan Africa	WI	WI	0.004	0.014	0.048
DMA	Dominica	Central America and the Caribbean	CREM	CREM	0.013	0.052	0.173
DMA	Dominica	Central America and the Caribbean	WASOTH	WASOTH	0.361	1.390	4.588
DMA	Dominica	Central America and the Caribbean	WI	WI	0.001	0.004	0.014
DNK	Denmark	EU27	CEM	CEM	10.563	20.120	124.895
DNK	Denmark	EU27	CREM	CREM	2.186	8.096	26.718
DNK	Denmark	EU27	OR	CO-OR	12.605	26.537	43.786
DNK	Denmark	EU27	SC-DR-coal	HC-DR	4.364	6.562	9.384
DNK	Denmark	EU27	SC-DR-gas	NG-DR	0.098	0.207	0.342
DNK	Denmark	EU27	SC-DR-oil	CO-HF-DR	0.532	1.120	1.848
DNK	Denmark	EU27	SC-DR-oil	CO-LF-DR	3.309	6.966	11.494
DNK	Denmark	EU27	SC-IND-coal	HC-IND	5.859	8.811	12.599
DNK	Denmark	EU27	SC-IND-gas	NG-IND	0.073	0.153	0.252
DNK	Denmark	EU27	SC-IND-oil	CO-HF-IND	0.893	1.881	3.104
DNK	Denmark	EU27	SC-IND-oil	CO-LF-IND	0.256	0.540	0.890
DNK	Denmark	EU27	SC-PP-coal	HC-B-PP	228.335	343.361	491.007
DNK	Denmark	EU27	SC-PP-gas	NG-PP	0.263	0.554	0.914
DNK	Denmark	EU27	SC-PP-oil	CO-HF-PP	2.035	4.284	7.069
DNK	Denmark	EU27	SC-PP-oil	CO-LF-PP	0.082	0.173	0.285
DNK	Denmark	EU27	WASOTH	WASOTH	11.944	57.297	222.231

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DNK	Denmark	EU27	WI	WI	4.335	20.795	80.655
DOM	Dominican Republic	Central America and the Caribbean	ASGM	ASGM	56.250	225.000	393.750
DOM	Dominican Republic	Central America and the Caribbean	CEM	CEM	75.600	208.800	759.720
DOM	Dominican Republic	Central America and the Caribbean	CREM	CREM	1.720	6.960	23.336
DOM	Dominican Republic	Central America and the Caribbean	NFMP-AU	GP-L	0.048	6.851	17.812
DOM	Dominican Republic	Central America and the Caribbean	OR	CO-OR	0.605	1.345	2.219
DOM	Dominican Republic	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.541	1.202	1.983
DOM	Dominican Republic	Central America and the Caribbean	SC-IND-gas	NG-IND	0.001	0.002	0.004
DOM	Dominican Republic	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	1.949	4.332	7.148
DOM	Dominican Republic	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.104	0.232	0.382
DOM	Dominican Republic	Central America and the Caribbean	SC-PP-coal	HC-B-PP	49.308	78.266	111.921
DOM	Dominican Republic	Central America and the Caribbean	SC-PP-gas	NG-PP	0.045	0.101	0.166
DOM	Dominican Republic	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	10.884	24.187	39.909
DOM	Dominican Republic	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.546	1.214	2.003
DOM	Dominican Republic	Central America and the Caribbean	WASOTH	WASOTH	49.925	192.020	633.666
DOM	Dominican Republic	Central America and the Caribbean	WI	WI	0.155	0.597	1.969
DZA	Algeria	North Africa	CEM	CEM	567.000	1566.000	5697.900
DZA	Algeria	North Africa	CREM	CREM	0.100	0.417	1.500
DZA	Algeria	North Africa	CSP	CSP-C	98.000	280.000	546.000
DZA	Algeria	North Africa	NFMP-AU	GP-L	0.389	55.550	144.430
DZA	Algeria	North Africa	NFMP-ZN	ZN-P	204.435	544.275	1337.456
DZA	Algeria	North Africa	OR	CO-OR	33.017	73.372	121.064
DZA	Algeria	North Africa	PISP	PIP	14.616	34.800	248.820
DZA	Algeria	North Africa	SC-DR-gas	NG-DR	0.586	1.302	2.148
DZA	Algeria	North Africa	SC-DR-oil	CO-LF-DR	5.781	12.846	21.196
DZA	Algeria	North Africa	SC-IND-gas	NG-IND	0.233	0.517	0.854
DZA	Algeria	North Africa	SC-IND-oil	CO-HF-IND	0.009	0.020	0.033
DZA	Algeria	North Africa	SC-IND-oil	CO-LF-IND	0.969	2.154	3.554
DZA	Algeria	North Africa	SC-PP-gas	NG-PP	1.480	3.288	5.425
DZA	Algeria	North Africa	SC-PP-oil	CO-LF-PP	0.222	0.494	0.815
DZA	Algeria	North Africa	SC-PP-oil	CO-PP	2.196	4.880	8.052
DZA	Algeria	North Africa	WASOTH	WASOTH	160.025	615.481	1969.539
DZA	Algeria	North Africa	WI	WI	0.497	1.913	6.120
ECU	Ecuador	South America	ASGM	ASGM	8750.000	17500.000	26250.000
ECU	Ecuador	South America	CEM	CEM	126.000	348.000	1266.200
ECU	Ecuador	South America	CREM	CREM	12.146	46.070	159.152
ECU	Ecuador	South America	NFMP-AU	GP-L	0.580	82.843	215.392
ECU	Ecuador	South America	OR	CO-OR	3.949	8.776	14.480
ECU	Ecuador	South America	SC-DR-oil	CO-LF-DR	2.284	5.076	8.375
ECU	Ecuador	South America	SC-IND-oil	CO-HF-IND	3.548	7.885	13.010
ECU	Ecuador	South America	SC-IND-oil	CO-LF-IND	0.547	1.216	2.006
ECU	Ecuador	South America	SC-PP-gas	NG-PP	0.046	0.101	0.167
ECU	Ecuador	South America	SC-PP-oil	CO-HF-PP	5.865	13.034	21.506
ECU	Ecuador	South America	SC-PP-oil	CO-LF-PP	0.367	0.815	1.345
ECU	Ecuador	South America	SC-PP-oil	CO-PP	2.112	4.693	7.743
ECU	Ecuador	South America	WASOTH	WASOTH	72.961	280.943	956.044
ECU	Ecuador	South America	WI	WI	0.227	0.873	2.971
EGY	Egypt	North Africa	CEM	CEM	1464.750	4045.500	14719.575
EGY	Egypt	North Africa	CREM	CREM	0.236	0.985	3.547
EGY	Egypt	North Africa	NFMP-AL	AL-P	4.655	13.300	25.935
EGY	Egypt	North Africa	OR	CO-OR	36.656	81.457	134.404
EGY	Egypt	North Africa	PISP	PIP	12.600	30.000	214.500
EGY	Egypt	North Africa	SC-DR-gas	NG-DR	0.122	0.271	0.447

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
EGY	Egypt	North Africa	SC-DR-oil	CO-HF-DR	4.977	11.060	18.249
EGY	Egypt	North Africa	SC-DR-oil	CO-LF-DR	7.978	17.728	29.251
EGY	Egypt	North Africa	SC-IND-gas	NG-IND	0.841	1.868	3.082
EGY	Egypt	North Africa	SC-IND-oil	CO-HF-IND	4.932	10.960	18.084
EGY	Egypt	North Africa	SC-IND-oil	CO-LF-IND	1.747	3.882	6.405
EGY	Egypt	North Africa	SC-PP-gas	NG-PP	2.499	5.554	9.163
EGY	Egypt	North Africa	SC-PP-oil	CO-HF-PP	51.966	115.480	190.542
EGY	Egypt	North Africa	SC-PP-oil	CO-LF-PP	0.603	1.340	2.211
EGY	Egypt	North Africa	WASOTH	WASOTH	269.778	1037.608	3320.345
EGY	Egypt	North Africa	WI	WI	0.838	3.224	10.318
ERI	Eritrea	Sub-Saharan Africa	CEM	CEM	1.418	3.915	14.245
ERI	Eritrea	Sub-Saharan Africa	CREM	CREM	0.004	0.014	0.050
ERI	Eritrea	Sub-Saharan Africa	NFMP-AU	GP-L	0.012	1.650	4.290
ERI	Eritrea	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.009	0.020	0.033
ERI	Eritrea	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.048	0.106	0.175
ERI	Eritrea	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.063	0.140	0.231
ERI	Eritrea	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.001	0.002	0.003
ERI	Eritrea	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	0.477	1.060	1.749
ERI	Eritrea	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.010	0.022	0.036
ERI	Eritrea	Sub-Saharan Africa	WASOTH	WASOTH	1.632	6.624	22.000
ERI	Eritrea	Sub-Saharan Africa	WI	WI	0.005	0.021	0.068
ESH	Western Sahara	Sub-Saharan Africa	CREM	CREM	0.000	0.000	0.000
ESH	Western Sahara	Sub-Saharan Africa	WASOTH	WASOTH	0.516	2.094	6.955
ESH	Western Sahara	Sub-Saharan Africa	WI	WI	0.002	0.007	0.022
ESP	Spain	EU27	CEM	CEM	498.658	1350.532	5132.023
ESP	Spain	EU27	CREM	CREM	4.764	17.646	58.232
ESP	Spain	EU27	CSP	CSP-C	281.417	804.049	1567.895
ESP	Spain	EU27	NFMP-AL	AL-P	1.488	4.250	8.288
ESP	Spain	EU27	NFMP-AU	GP-L	0.066	9.488	24.668
ESP	Spain	EU27	NFMP-CU	CU-P	179.229	502.686	2516.249
ESP	Spain	EU27	NFMP-ZN	ZN-T	709.534	1359.306	2887.940
ESP	Spain	EU27	OR	CO-OR	85.031	179.013	295.372
ESP	Spain	EU27	PISP	PIP	38.481	91.622	655.096
ESP	Spain	EU27	SC-DR-coal	HC-DR	39.277	59.063	84.459
ESP	Spain	EU27	SC-DR-gas	NG-DR	0.514	1.082	1.786
ESP	Spain	EU27	SC-DR-oil	CO-HF-DR	4.085	8.600	14.190
ESP	Spain	EU27	SC-DR-oil	CO-LF-DR	27.346	57.570	94.991
ESP	Spain	EU27	SC-IND-coal	HC-IND	11.995	18.038	25.794
ESP	Spain	EU27	SC-IND-gas	NG-IND	0.912	1.921	3.169
ESP	Spain	EU27	SC-IND-oil	CO-HF-IND	9.070	19.095	31.507
ESP	Spain	EU27	SC-IND-oil	CO-IND	0.054	0.114	0.188
ESP	Spain	EU27	SC-IND-oil	CO-LF-IND	0.907	1.910	3.151
ESP	Spain	EU27	SC-PP-coal	BC-S-PP	101.668	152.884	218.624
ESP	Spain	EU27	SC-PP-coal	HC-A-PP	70.551	106.092	151.712
ESP	Spain	EU27	SC-PP-coal	HC-B-PP	435.850	655.414	937.242
ESP	Spain	EU27	SC-PP-gas	NG-PP	1.977	4.162	6.868
ESP	Spain	EU27	SC-PP-oil	CO-HF-PP	21.897	46.098	76.062
ESP	Spain	EU27	SC-PP-oil	CO-LF-PP	0.960	2.021	3.335
ESP	Spain	EU27	WASOTH	WASOTH	80.622	386.765	1500.102
ESP	Spain	EU27	WI	WI	29.260	140.369	544.434
EST	Estonia	EU27	CEM	CEM	5.165	14.266	51.907
EST	Estonia	EU27	CREM	CREM	0.345	1.276	4.212
EST	Estonia	EU27	SC-DR-coal	HC-DR	0.873	1.313	1.877

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
EST	Estonia	EU27	SC-DR-gas	NG-DR	0.009	0.020	0.033
EST	Estonia	EU27	SC-DR-oil	CO-HF-DR	0.029	0.060	0.099
EST	Estonia	EU27	SC-DR-oil	CO-LF-DR	0.462	0.972	1.604
EST	Estonia	EU27	SC-IND-coal	BC-IND	11.697	17.589	25.153
EST	Estonia	EU27	SC-IND-coal	HC-IND	3.460	5.203	7.440
EST	Estonia	EU27	SC-IND-gas	NG-IND	0.011	0.023	0.038
EST	Estonia	EU27	SC-IND-oil	CO-HF-IND	0.099	0.209	0.345
EST	Estonia	EU27	SC-IND-oil	CO-LF-IND	0.037	0.078	0.129
EST	Estonia	EU27	SC-PP-coal	BC-L-PP	546.901	822.407	1176.043
EST	Estonia	EU27	SC-PP-coal	HC-B-PP	0.069	0.104	0.148
EST	Estonia	EU27	SC-PP-gas	NG-PP	0.036	0.076	0.126
EST	Estonia	EU27	SC-PP-oil	CO-HF-PP	0.522	1.098	1.812
EST	Estonia	EU27	SC-PP-oil	CO-LF-PP	0.012	0.025	0.042
EST	Estonia	EU27	WASOTH	WASOTH	1.464	7.023	27.241
EST	Estonia	EU27	WI	WI	0.531	2.549	9.887
ETH	Ethiopia	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
ETH	Ethiopia	Sub-Saharan Africa	CEM	CEM	72.450	200.100	728.065
ETH	Ethiopia	Sub-Saharan Africa	CREM	CREM	1.414	5.656	19.797
ETH	Ethiopia	Sub-Saharan Africa	NFMP-AU	GP-L	1.309	187.000	486.200
ETH	Ethiopia	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	1.049	2.332	3.848
ETH	Ethiopia	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	1.458	3.240	5.346
ETH	Ethiopia	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.349	0.776	1.280
ETH	Ethiopia	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.138	0.306	0.505
ETH	Ethiopia	Sub-Saharan Africa	WASOTH	WASOTH	49.141	199.412	662.332
ETH	Ethiopia	Sub-Saharan Africa	WI	WI	0.153	0.620	2.058
FIN	Finland	EU27	CEM	CEM	30.809	83.624	346.158
FIN	Finland	EU27	CREM	CREM	1.080	4.001	13.202
FIN	Finland	EU27	CSP	CSP-C	17.500	50.000	97.500
FIN	Finland	EU27	NFMP-AU	GP-L	0.135	19.250	50.050
FIN	Finland	EU27	NFMP-CU	CU-P	94.565	265.229	1327.635
FIN	Finland	EU27	NFMP-ZN	ZN-P	245.363	653.238	1605.214
FIN	Finland	EU27	OR	CO-OR	17.666	37.193	61.368
FIN	Finland	EU27	PISP	PIP	27.622	65.767	470.231
FIN	Finland	EU27	SC-DR-coal	HC-DR	0.611	0.919	1.314
FIN	Finland	EU27	SC-DR-gas	NG-DR	0.010	0.021	0.035
FIN	Finland	EU27	SC-DR-oil	CO-HF-DR	1.910	4.020	6.633
FIN	Finland	EU27	SC-DR-oil	CO-LF-DR	3.338	7.028	11.596
FIN	Finland	EU27	SC-IND-coal	HC-IND	5.167	7.770	11.111
FIN	Finland	EU27	SC-IND-gas	NG-IND	0.065	0.137	0.227
FIN	Finland	EU27	SC-IND-oil	CO-HF-IND	2.870	6.042	9.969
FIN	Finland	EU27	SC-IND-oil	CO-LF-IND	0.389	0.819	1.351
FIN	Finland	EU27	SC-PP-coal	HC-B-PP	153.451	230.753	329.977
FIN	Finland	EU27	SC-PP-gas	NG-PP	0.280	0.589	0.972
FIN	Finland	EU27	SC-PP-oil	CO-HF-PP	3.882	8.172	13.484
FIN	Finland	EU27	SC-PP-oil	CO-LF-PP	0.031	0.065	0.107
FIN	Finland	EU27	WASOTH	WASOTH	10.727	51.460	199.591
FIN	Finland	EU27	WI	WI	3.893	18.676	72.438
FJI	Fiji	Australia, New Zealand & Oceania	CEM	CEM	3.032	8.374	30.468
FJI	Fiji	Australia, New Zealand & Oceania	CREM	CREM	0.668	2.971	11.141
FJI	Fiji	Australia, New Zealand & Oceania	NFMP-AU	GP-L	0.360	51.480	133.848
FJI	Fiji	Australia, New Zealand & Oceania	WASOTH	WASOTH	2.172	7.842	27.145
FJI	Fiji	Australia, New Zealand & Oceania	WI	WI	0.007	0.024	0.084
FLK	Falkland Is. (Malvinas)	South America	CREM	CREM	0.001	0.003	0.011

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
FLK	Falkland Is. (Malvinas)	South America	WASOTH	WASOTH	0.065	0.252	0.857
FLK	Falkland Is. (Malvinas)	South America	WI	WI	0.000	0.001	0.003
FRA	France	EU27	CEM	CEM	579.909	1592.448	11595.413
FRA	France	EU27	CREM	CREM	9.248	34.252	113.032
FRA	France	EU27	CSP	CSP-C	301.267	860.763	1678.487
FRA	France	EU27	NFMP-AL	AL-P	1.558	4.450	8.678
FRA	France	EU27	NFMP-AU	GP-L	0.029	4.125	10.725
FRA	France	EU27	NFMP-ZN	ZN-P	133.888	356.454	875.921
FRA	France	EU27	OR	CO-OR	116.492	245.245	404.655
FRA	France	EU27	PISP	PIP	109.206	260.014	1859.100
FRA	France	EU27	SC-DR-coal	HC-DR	41.895	63.000	90.090
FRA	France	EU27	SC-DR-gas	NG-DR	2.598	5.470	9.026
FRA	France	EU27	SC-DR-oil	CO-HF-DR	5.748	12.100	19.965
FRA	France	EU27	SC-DR-oil	CO-LF-DR	40.670	85.620	141.273
FRA	France	EU27	SC-IND-coal	BC-IND	3.752	5.642	8.068
FRA	France	EU27	SC-IND-coal	HC-IND	92.546	139.166	199.008
FRA	France	EU27	SC-IND-gas	NG-IND	0.730	1.537	2.536
FRA	France	EU27	SC-IND-oil	CO-HF-IND	8.998	18.943	31.256
FRA	France	EU27	SC-IND-oil	CO-LF-IND	1.307	2.751	4.539
FRA	France	EU27	SC-PP-coal	HC-B-PP	279.405	420.158	600.826
FRA	France	EU27	SC-PP-gas	NG-PP	0.729	1.534	2.531
FRA	France	EU27	SC-PP-oil	CO-HF-PP	14.108	29.700	49.005
FRA	France	EU27	SC-PP-oil	CO-LF-PP	0.116	0.245	0.404
FRA	France	EU27	WASOTH	WASOTH	119.698	574.221	2227.170
FRA	France	EU27	WI	WI	43.442	208.403	808.310
FRO	Faeroe Islands	CIS & other European countries	CREM	CREM	0.004	0.014	0.045
FRO	Faeroe Islands	CIS & other European countries	WASOTH	WASOTH	0.120	0.465	1.587
FRO	Faeroe Islands	CIS & other European countries	WI	WI	0.044	0.169	0.576
FSM	Federated States of Micronesia	Australia, New Zealand & Oceania	CREM	CREM	0.096	0.427	1.600
FSM	Federated States of Micronesia	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.134	0.483	1.671
FSM	Federated States of Micronesia	Australia, New Zealand & Oceania	WI	WI	0.000	0.002	0.005
GAB	Gabon	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
GAB	Gabon	Sub-Saharan Africa	CEM	CEM	7.245	20.010	72.807
GAB	Gabon	Sub-Saharan Africa	CREM	CREM	0.046	0.186	0.651
GAB	Gabon	Sub-Saharan Africa	NFMP-AU	GP-L	0.116	16.500	42.900
GAB	Gabon	Sub-Saharan Africa	OR	CO-OR	0.848	1.884	3.108
GAB	Gabon	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.095	0.212	0.350
GAB	Gabon	Sub-Saharan Africa	SC-IND-gas	NG-IND	0.000	0.000	0.001
GAB	Gabon	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.306	0.680	1.122
GAB	Gabon	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.131	0.292	0.482
GAB	Gabon	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.016	0.035	0.057
GAB	Gabon	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	0.162	0.360	0.594
GAB	Gabon	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.047	0.104	0.172
GAB	Gabon	Sub-Saharan Africa	WASOTH	WASOTH	12.883	52.279	173.641
GAB	Gabon	Sub-Saharan Africa	WI	WI	0.040	0.162	0.540
GBR	United Kingdom	EU27	CEM	CEM	135.787	370.002	1713.862
GBR	United Kingdom	EU27	CREM	CREM	23.165	85.797	283.132
GBR	United Kingdom	EU27	CSP	CSP-C	242.375	692.500	1350.375
GBR	United Kingdom	EU27	NFMP-AL	AL-P	0.814	2.325	4.534
GBR	United Kingdom	EU27	NFMP-AU	GP-L	0.004	0.509	1.323
GBR	United Kingdom	EU27	NFMP-PB	PB-P	10.631	30.375	59.231
GBR	United Kingdom	EU27	OR	CO-OR	114.206	240.434	396.717
GBR	United Kingdom	EU27	PISP	PIP	77.921	185.526	1326.514

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
GBR	United Kingdom	EU27	SC-DR-coal	HC-DR	67.294	101.194	144.707
GBR	United Kingdom	EU27	SC-DR-gas	NG-DR	3.573	7.523	12.412
GBR	United Kingdom	EU27	SC-DR-oil	CO-HF-DR	6.128	12.900	21.285
GBR	United Kingdom	EU27	SC-DR-oil	CO-LF-DR	21.596	45.466	75.019
GBR	United Kingdom	EU27	SC-IND-coal	HC-IND	80.920	121.684	174.008
GBR	United Kingdom	EU27	SC-IND-gas	NG-IND	0.979	2.060	3.399
GBR	United Kingdom	EU27	SC-IND-oil	CO-HF-IND	3.628	7.638	12.603
GBR	United Kingdom	EU27	SC-IND-oil	CO-LF-IND	2.228	4.691	7.740
GBR	United Kingdom	EU27	SC-PP-coal	HC-B-PP	1381.643	2077.659	2971.052
GBR	United Kingdom	EU27	SC-PP-gas	NG-PP	3.847	8.100	13.364
GBR	United Kingdom	EU27	SC-PP-oil	CO-HF-PP	12.560	26.442	43.629
GBR	United Kingdom	EU27	SC-PP-oil	CO-LF-PP	0.032	0.067	0.110
GBR	United Kingdom	EU27	WASOTH	WASOTH	121.868	584.628	2267.534
GBR	United Kingdom	EU27	WI	WI	44.230	212.180	822.960
GEO	Georgia	CIS & other European countries	CEM	CEM	12.403	34.256	124.642
GEO	Georgia	CIS & other European countries	CREM	CREM	0.456	1.521	5.019
GEO	Georgia	CIS & other European countries	NFMP-AU	GP-L	0.693	99.000	257.400
GEO	Georgia	CIS & other European countries	OR	CO-OR	0.023	0.051	0.084
GEO	Georgia	CIS & other European countries	SC-DR-coal	HC-DR	16.632	26.400	37.752
GEO	Georgia	CIS & other European countries	SC-DR-gas	NG-DR	0.030	0.067	0.110
GEO	Georgia	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.283	0.628	1.036
GEO	Georgia	CIS & other European countries	SC-IND-coal	HC-IND	4.134	6.562	9.384
GEO	Georgia	CIS & other European countries	SC-IND-gas	NG-IND	0.019	0.042	0.069
GEO	Georgia	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.270	0.600	0.990
GEO	Georgia	CIS & other European countries	SC-PP-gas	NG-PP	0.051	0.113	0.187
GEO	Georgia	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.059	0.132	0.218
GEO	Georgia	CIS & other European countries	WASOTH	WASOTH	10.491	40.564	138.476
GEO	Georgia	CIS & other European countries	WI	WI	0.033	0.126	0.430
GHA	Ghana	Sub-Saharan Africa	ASGM	ASGM	36750.000	52500.000	68250.000
GHA	Ghana	Sub-Saharan Africa	CEM	CEM	56.700	156.600	569.790
GHA	Ghana	Sub-Saharan Africa	CREM	CREM	0.039	0.154	0.540
GHA	Ghana	Sub-Saharan Africa	NFMP-AU	GP-L	33.110	4730.000	12298.000
GHA	Ghana	Sub-Saharan Africa	OR	CO-OR	0.139	0.309	0.509
GHA	Ghana	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.844	1.876	3.095
GHA	Ghana	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.360	0.800	1.320
GHA	Ghana	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.307	0.682	1.125
GHA	Ghana	Sub-Saharan Africa	SC-PP-oil	CO-PP	2.430	5.400	8.910
GHA	Ghana	Sub-Saharan Africa	WASOTH	WASOTH	22.729	92.232	306.342
GHA	Ghana	Sub-Saharan Africa	WI	WI	0.071	0.287	0.952
GIB	Gibraltar	CIS & other European countries	CREM	CREM	0.002	0.008	0.026
GIB	Gibraltar	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.066	0.146	0.241
GIB	Gibraltar	CIS & other European countries	SC-PP-oil	CO-HF-PP	0.340	0.756	1.247
GIB	Gibraltar	CIS & other European countries	WASOTH	WASOTH	0.096	0.373	1.272
GIB	Gibraltar	CIS & other European countries	WI	WI	0.035	0.135	0.462
GIN	Guinea	Sub-Saharan Africa	ASGM	ASGM	112.500	225.000	337.500
GIN	Guinea	Sub-Saharan Africa	CEM	CEM	12.600	34.800	126.620
GIN	Guinea	Sub-Saharan Africa	CREM	CREM	0.107	0.429	1.500
GIN	Guinea	Sub-Saharan Africa	NFMP-AU	GP-L	6.962	994.565	2585.869
GIN	Guinea	Sub-Saharan Africa	WASOTH	WASOTH	6.195	25.140	83.501
GIN	Guinea	Sub-Saharan Africa	WI	WI	0.019	0.078	0.259
GLP	Guadeloupe	Central America and the Caribbean	CEM	CEM	5.796	16.008	58.245
GLP	Guadeloupe	Central America and the Caribbean	CREM	CREM	0.071	0.286	0.958
GMB	Gambia	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
GMB	Gambia	Sub-Saharan Africa	CREM	CREM	0.006	0.024	0.084
GMB	Gambia	Sub-Saharan Africa	WASOTH	WASOTH	1.387	5.630	18.700
GMB	Gambia	Sub-Saharan Africa	WI	WI	0.004	0.017	0.058
GNB	Guinea-Bissau	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
GNB	Guinea-Bissau	Sub-Saharan Africa	CREM	CREM	0.009	0.037	0.128
GNB	Guinea-Bissau	Sub-Saharan Africa	WASOTH	WASOTH	1.023	4.150	13.786
GNB	Guinea-Bissau	Sub-Saharan Africa	WI	WI	0.003	0.013	0.043
GNQ	Equatorial Guinea	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
GNQ	Equatorial Guinea	Sub-Saharan Africa	CREM	CREM	0.023	0.094	0.327
GNQ	Equatorial Guinea	Sub-Saharan Africa	NFMP-AU	GP-L	0.077	11.000	28.600
GNQ	Equatorial Guinea	Sub-Saharan Africa	WASOTH	WASOTH	13.843	56.176	186.584
GNQ	Equatorial Guinea	Sub-Saharan Africa	WI	WI	0.043	0.175	0.580
GRC	Greece	EU27	CEM	CEM	253.512	700.176	2547.594
GRC	Greece	EU27	CSP	CSP-C	34.912	99.748	194.508
GRC	Greece	EU27	NFMP-AL	AL-P	4.095	10.400	21.548
GRC	Greece	EU27	NFMP-AU	GP-L	0.010	1.375	3.575
GRC	Greece	EU27	OR	CO-OR	27.794	58.514	96.548
GRC	Greece	EU27	SC-DR-coal	BC-DR	1.848	2.779	3.974
GRC	Greece	EU27	SC-DR-coal	HC-DR	0.175	0.263	0.375
GRC	Greece	EU27	SC-DR-gas	NG-DR	0.046	0.097	0.160
GRC	Greece	EU27	SC-DR-oil	CO-HF-DR	6.318	13.300	21.945
GRC	Greece	EU27	SC-DR-oil	CO-LF-DR	5.655	11.906	19.645
GRC	Greece	EU27	SC-IND-coal	BC-IND	2.133	3.208	4.588
GRC	Greece	EU27	SC-IND-coal	HC-IND	12.041	18.107	25.893
GRC	Greece	EU27	SC-IND-gas	NG-IND	0.045	0.095	0.157
GRC	Greece	EU27	SC-IND-oil	CO-HF-IND	3.854	8.113	13.386
GRC	Greece	EU27	SC-IND-oil	CO-LF-IND	0.311	0.656	1.082
GRC	Greece	EU27	SC-PP-coal	BC-L-PP	3614.116	5434.761	7771.708
GRC	Greece	EU27	SC-PP-coal	HC-B-PP	2.547	3.830	5.476
GRC	Greece	EU27	SC-PP-gas	NG-PP	0.204	0.429	0.707
GRC	Greece	EU27	SC-PP-oil	CO-HF-PP	15.125	31.842	52.539
GRC	Greece	EU27	SC-PP-oil	CO-LF-PP	0.309	0.650	1.072
GRC	Greece	EU27	WASOTH	WASOTH	17.169	82.365	319.462
GRC	Greece	EU27	WI	WI	6.231	29.893	115.943
GRD	Grenada	Central America and the Caribbean	CREM	CREM	0.016	0.064	0.214
GRD	Grenada	Central America and the Caribbean	WASOTH	WASOTH	0.460	1.770	5.839
GRD	Grenada	Central America and the Caribbean	WI	WI	0.001	0.005	0.018
GRL	Greenland	North America	CREM	CREM	0.025	0.091	0.305
GRL	Greenland	North America	WASOTH	WASOTH	0.847	3.536	12.740
GRL	Greenland	North America	WI	WI	0.003	0.011	0.040
GTM	Guatemala	Central America and the Caribbean	ASGM	ASGM	187.500	750.000	1312.500
GTM	Guatemala	Central America and the Caribbean	CEM	CEM	37.800	104.400	379.860
GTM	Guatemala	Central America and the Caribbean	CREM	CREM	2.371	9.596	32.173
GTM	Guatemala	Central America and the Caribbean	NFMP-AU	GP-L	2.352	336.006	873.616
GTM	Guatemala	Central America and the Caribbean	OR	CO-OR	0.041	0.091	0.150
GTM	Guatemala	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.880	1.956	3.227
GTM	Guatemala	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	1.744	3.876	6.395
GTM	Guatemala	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.082	0.182	0.301
GTM	Guatemala	Central America and the Caribbean	SC-PP-coal	HC-B-PP	18.754	29.768	42.568
GTM	Guatemala	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	6.361	14.136	23.324
GTM	Guatemala	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.064	0.143	0.235
GTM	Guatemala	Central America and the Caribbean	WASOTH	WASOTH	36.960	142.154	469.109
GTM	Guatemala	Central America and the Caribbean	WI	WI	0.115	0.442	1.458

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
GUF	French Guiana	Central America and the Caribbean	ASGM	ASGM	2812.500	5625.000	8437.500
GUF	French Guiana	Central America and the Caribbean	CEM	CEM	1.562	4.315	15.701
GUF	French Guiana	Central America and the Caribbean	CREM	CREM	0.035	0.140	0.471
GUF	French Guiana	Central America and the Caribbean	NFMP-AU	GP-L	0.554	79.200	205.920
GUY	Guyana	Central America and the Caribbean	ASGM	ASGM	5625.000	11250.000	16875.000
GUY	Guyana	Central America and the Caribbean	CREM	CREM	0.068	0.275	0.921
GUY	Guyana	Central America and the Caribbean	NFMP-AU	GP-L	2.268	324.047	842.522
GUY	Guyana	Central America and the Caribbean	WASOTH	WASOTH	1.264	4.863	16.046
GUY	Guyana	Central America and the Caribbean	WI	WI	0.004	0.015	0.050
HKG	Hong Kong (additional to China)	East and Southeast Asia	CEM	CEM	19.320	52.200	185.640
HKG	Hong Kong (additional to China)	East and Southeast Asia	CREM	CREM	2.155	7.761	24.673
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-DR-oil	CO-LF-DR	1.409	3.132	5.168
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-IND-coal	HC-IND	151.717	240.821	344.374
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.537	1.193	1.969
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-PP-coal	HC-B-PP	365.086	579.501	828.686
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-PP-gas	NG-PP	0.227	0.506	0.834
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-PP-oil	CO-HF-PP	0.248	0.551	0.909
HKG	Hong Kong (additional to China)	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.012	0.027	0.044
HKG	Hong Kong (additional to China)	East and Southeast Asia	WASOTH	WASOTH	183.694	727.124	2505.832
HKG	Hong Kong (additional to China)	East and Southeast Asia	WI	WI	5.292	20.948	72.192
HND	Honduras	Central America and the Caribbean	ASGM	ASGM	37.500	150.000	262.500
HND	Honduras	Central America and the Caribbean	CEM	CEM	45.360	125.280	455.832
HND	Honduras	Central America and the Caribbean	CREM	CREM	1.256	5.084	17.045
HND	Honduras	Central America and the Caribbean	NFMP-AU	GP-L	0.590	84.229	218.996
HND	Honduras	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.270	0.600	0.990
HND	Honduras	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.551	1.224	2.020
HND	Honduras	Central America and the Caribbean	SC-IND-coal	HC-IND	7.300	11.588	16.570
HND	Honduras	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	1.539	3.420	5.643
HND	Honduras	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.056	0.124	0.204
HND	Honduras	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	6.088	13.528	22.321
HND	Honduras	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.020	0.044	0.072
HND	Honduras	Central America and the Caribbean	WASOTH	WASOTH	16.023	61.627	203.370
HND	Honduras	Central America and the Caribbean	WI	WI	0.050	0.192	0.632
HRV	Croatia	CIS & other European countries	CEM	CEM	77.175	213.150	775.548
HRV	Croatia	CIS & other European countries	CREM	CREM	1.514	5.046	16.653
HRV	Croatia	CIS & other European countries	OR	CO-OR	7.183	15.963	26.339
HRV	Croatia	CIS & other European countries	SC-DR-coal	BC-DR	1.134	1.800	2.574
HRV	Croatia	CIS & other European countries	SC-DR-gas	NG-DR	0.075	0.167	0.275
HRV	Croatia	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.198	0.440	0.726
HRV	Croatia	CIS & other European countries	SC-DR-oil	CO-LF-DR	1.456	3.236	5.339
HRV	Croatia	CIS & other European countries	SC-IND-coal	BC-IND	3.317	5.265	7.529
HRV	Croatia	CIS & other European countries	SC-IND-coal	HC-IND	13.147	20.869	29.842
HRV	Croatia	CIS & other European countries	SC-IND-gas	NG-IND	0.053	0.118	0.194
HRV	Croatia	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.792	1.760	2.904
HRV	Croatia	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.149	0.332	0.548
HRV	Croatia	CIS & other European countries	SC-PP-coal	BC-L-PP	0.062	0.098	0.140
HRV	Croatia	CIS & other European countries	SC-PP-coal	HC-B-PP	45.360	72.000	102.960

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
HRV	Croatia	CIS & other European countries	SC-PP-gas	NG-PP	0.083	0.185	0.305
HRV	Croatia	CIS & other European countries	SC-PP-oil	CO-HF-PP	6.813	15.140	24.981
HRV	Croatia	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.005	0.012	0.020
HRV	Croatia	CIS & other European countries	WASOTH	WASOTH	26.187	101.257	345.672
HRV	Croatia	CIS & other European countries	WI	WI	0.754	2.917	9.959
HTI	Haiti	Central America and the Caribbean	CEM	CEM	8.269	22.838	83.094
HTI	Haiti	Central America and the Caribbean	CREM	CREM	1.706	6.906	23.155
HTI	Haiti	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.168	0.374	0.617
HTI	Haiti	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	0.036	0.080	0.132
HTI	Haiti	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.125	0.278	0.459
HTI	Haiti	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	0.225	0.500	0.825
HTI	Haiti	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.090	0.200	0.330
HTI	Haiti	Central America and the Caribbean	WASOTH	WASOTH	5.970	22.962	75.775
HTI	Haiti	Central America and the Caribbean	WI	WI	0.019	0.071	0.235
HUN	Hungary	EU27	CEM	CEM	56.336	152.912	632.975
HUN	Hungary	EU27	CREM	CREM	2.602	9.638	31.805
HUN	Hungary	EU27	CSP	CSP-C	114.625	327.500	638.625
HUN	Hungary	EU27	OR	CO-OR	10.213	21.502	35.478
HUN	Hungary	EU27	PISP	PIP	14.274	33.986	243.002
HUN	Hungary	EU27	SC-DR-coal	BC-DR	28.399	42.705	61.068
HUN	Hungary	EU27	SC-DR-coal	HC-DR	4.800	7.219	10.323
HUN	Hungary	EU27	SC-DR-gas	NG-DR	0.539	1.135	1.873
HUN	Hungary	EU27	SC-DR-oil	CO-HF-DR	0.019	0.040	0.066
HUN	Hungary	EU27	SC-DR-oil	CO-LF-DR	2.672	5.626	9.283
HUN	Hungary	EU27	SC-IND-coal	BC-IND	3.973	5.974	8.542
HUN	Hungary	EU27	SC-IND-coal	HC-IND	2.537	3.816	5.456
HUN	Hungary	EU27	SC-IND-gas	NG-IND	0.098	0.206	0.340
HUN	Hungary	EU27	SC-IND-oil	CO-HF-IND	0.117	0.247	0.408
HUN	Hungary	EU27	SC-IND-oil	CO-LF-IND	0.027	0.057	0.094
HUN	Hungary	EU27	SC-PP-coal	BC-L-PP	485.672	730.334	1044.377
HUN	Hungary	EU27	SC-PP-coal	BC-S-PP	15.892	23.898	34.175
HUN	Hungary	EU27	SC-PP-coal	HC-B-PP	7.124	10.712	15.319
HUN	Hungary	EU27	SC-PP-gas	NG-PP	0.319	0.671	1.108
HUN	Hungary	EU27	SC-PP-oil	CO-HF-PP	1.796	3.780	6.237
HUN	Hungary	EU27	SC-PP-oil	CO-LF-PP	0.044	0.094	0.154
HUN	Hungary	EU27	WASOTH	WASOTH	11.088	53.193	206.313
HUN	Hungary	EU27	WI	WI	4.024	19.305	74.877
IDN	Indonesia	East and Southeast Asia	ASGM	ASGM	40833.333	58333.333	75833.333
IDN	Indonesia	East and Southeast Asia	CEM	CEM	1008.000	2784.000	10129.600
IDN	Indonesia	East and Southeast Asia	CREM	CREM	10.025	36.111	114.800
IDN	Indonesia	East and Southeast Asia	CSP	CSP-C	43.750	125.000	243.750
IDN	Indonesia	East and Southeast Asia	NFMP-AL	AL-P	2.205	6.300	12.285
IDN	Indonesia	East and Southeast Asia	NFMP-AU	GP-L	36.036	5148.000	13384.800
IDN	Indonesia	East and Southeast Asia	NFMP-CU	CU-P	959.530	2691.211	13471.143
IDN	Indonesia	East and Southeast Asia	OR	CO-OR	68.250	151.667	250.251
IDN	Indonesia	East and Southeast Asia	SC-DR-gas	NG-DR	0.013	0.029	0.048
IDN	Indonesia	East and Southeast Asia	SC-DR-oil	CO-HF-DR	1.845	4.100	6.765
IDN	Indonesia	East and Southeast Asia	SC-DR-oil	CO-LF-DR	12.332	27.404	45.217
IDN	Indonesia	East and Southeast Asia	SC-IND-coal	BC-IND	1540.634	2445.450	3496.994
IDN	Indonesia	East and Southeast Asia	SC-IND-coal	HC-IND	34.304	54.450	77.864
IDN	Indonesia	East and Southeast Asia	SC-IND-gas	NG-IND	1.283	2.850	4.703
IDN	Indonesia	East and Southeast Asia	SC-IND-oil	CO-HF-IND	9.721	21.603	35.645
IDN	Indonesia	East and Southeast Asia	SC-IND-oil	CO-LF-IND	4.437	9.861	16.271

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
IDN	Indonesia	East and Southeast Asia	SC-PP-coal	BC-S-PP	2470.464	3921.372	5607.562
IDN	Indonesia	East and Southeast Asia	SC-PP-gas	NG-PP	1.976	4.390	7.244
IDN	Indonesia	East and Southeast Asia	SC-PP-oil	CO-HF-PP	30.301	67.336	111.104
IDN	Indonesia	East and Southeast Asia	SC-PP-oil	CO-LF-PP	4.812	10.693	17.644
IDN	Indonesia	East and Southeast Asia	WASOTH	WASOTH	579.854	2295.254	7909.961
IDN	Indonesia	East and Southeast Asia	WI	WI	16.705	66.125	227.883
IND	India	South Asia	ASGM	ASGM	562.500	1125.000	1687.500
IND	India	South Asia	CEM	CEM	4859.269	13420.838	48831.794
IND	India	South Asia	CREM	CREM	144.319	607.658	2126.805
IND	India	South Asia	CSP	CSP-C	329.000	940.000	1833.000
IND	India	South Asia	NFMP-AL	AL-P	182.700	464.000	961.350
IND	India	South Asia	NFMP-AU	GP-L	1.078	154.000	400.400
IND	India	South Asia	NFMP-CU	CU-P	3900.437	10939.627	54759.476
IND	India	South Asia	NFMP-PB	PB-P	59.941	168.563	366.095
IND	India	South Asia	NFMP-ZN	ZN-T	4060.264	10809.794	26563.090
IND	India	South Asia	OR	CO-OR	285.440	634.311	1046.613
IND	India	South Asia	PISP	PIP	812.385	1934.250	13829.888
IND	India	South Asia	SC-DR-coal	HC-DR	10101.244	16033.720	22928.220
IND	India	South Asia	SC-DR-gas	NG-DR	0.225	0.501	0.826
IND	India	South Asia	SC-DR-oil	CO-HF-DR	28.845	64.100	105.765
IND	India	South Asia	SC-DR-oil	CO-LF-DR	32.125	71.388	117.790
IND	India	South Asia	SC-IND-coal	BC-IND	812.567	1289.790	1844.399
IND	India	South Asia	SC-IND-coal	HC-IND	14286.621	22677.176	32428.362
IND	India	South Asia	SC-IND-gas	NG-IND	0.682	1.516	2.502
IND	India	South Asia	SC-IND-oil	CO-HF-IND	61.281	136.180	224.697
IND	India	South Asia	SC-IND-oil	CO-LF-IND	13.769	30.598	50.487
IND	India	South Asia	SC-PP-coal	BC-L-PP	5075.445	8056.262	11520.455
IND	India	South Asia	SC-PP-coal	HC-B-PP	26074.147	41387.535	59184.175
IND	India	South Asia	SC-PP-gas	NG-PP	2.901	6.447	10.638
IND	India	South Asia	SC-PP-oil	CO-HF-PP	12.996	28.880	47.652
IND	India	South Asia	SC-PP-oil	CO-LF-PP	7.445	16.544	27.298
IND	India	South Asia	WASOTH	WASOTH	3246.913	13691.802	48508.099
IND	India	South Asia	WI	WI	10.090	42.547	150.738
IRL	Ireland	EU27	CEM	CEM	79.223	218.805	796.123
IRL	Ireland	EU27	CREM	CREM	0.227	0.842	2.780
IRL	Ireland	EU27	OR	CO-OR	4.541	9.561	15.775
IRL	Ireland	EU27	SC-DR-coal	BC-DR	2.431	3.656	5.228
IRL	Ireland	EU27	SC-DR-coal	HC-DR	27.843	41.869	59.872
IRL	Ireland	EU27	SC-DR-gas	NG-DR	0.115	0.243	0.401
IRL	Ireland	EU27	SC-DR-oil	CO-HF-DR	0.304	0.640	1.056
IRL	Ireland	EU27	SC-DR-oil	CO-LF-DR	3.021	6.360	10.494
IRL	Ireland	EU27	SC-IND-coal	HC-IND	7.751	11.655	16.667
IRL	Ireland	EU27	SC-IND-gas	NG-IND	0.058	0.123	0.203
IRL	Ireland	EU27	SC-IND-oil	CO-HF-IND	2.022	4.256	7.022
IRL	Ireland	EU27	SC-IND-oil	CO-LF-IND	0.168	0.353	0.583
IRL	Ireland	EU27	SC-PP-coal	HC-B-PP	47.353	71.208	101.827
IRL	Ireland	EU27	SC-PP-gas	NG-PP	0.304	0.640	1.057
IRL	Ireland	EU27	SC-PP-oil	CO-HF-PP	1.984	4.176	6.890
IRL	Ireland	EU27	SC-PP-oil	CO-LF-PP	0.010	0.022	0.036
IRL	Ireland	EU27	WASOTH	WASOTH	9.713	46.594	180.718
IRL	Ireland	EU27	WI	WI	3.525	16.910	65.588
IRN	Iran	Middle Eastern States	CEM	CEM	1260.000	3480.000	12662.000
IRN	Iran	Middle Eastern States	CREM	CREM	0.748	3.325	11.844

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
IRN	Iran	Middle Eastern States	CSP	CSP-C	581.000	1660.000	3237.000
IRN	Iran	Middle Eastern States	NFMP-AL	AL-P	15.750	40.000	82.875
IRN	Iran	Middle Eastern States	NFMP-AU	GP-L	0.111	15.840	41.184
IRN	Iran	Middle Eastern States	NFMP-CU	CU-T	843.115	2364.700	11836.760
IRN	Iran	Middle Eastern States	NFMP-PB	PB-P	9.386	26.563	55.333
IRN	Iran	Middle Eastern States	NFMP-ZN	ZN-T	255.255	679.575	1669.931
IRN	Iran	Middle Eastern States	OR	CO-OR	15.807	35.127	57.960
IRN	Iran	Middle Eastern States	PISP	PIP	46.673	111.125	794.544
IRN	Iran	Middle Eastern States	SC-DR-coal	HC-DR	1.323	2.100	3.003
IRN	Iran	Middle Eastern States	SC-DR-gas	NG-DR	4.544	10.097	16.660
IRN	Iran	Middle Eastern States	SC-DR-oil	CO-HF-DR	10.512	23.360	38.544
IRN	Iran	Middle Eastern States	SC-DR-oil	CO-LF-DR	19.733	43.850	72.353
IRN	Iran	Middle Eastern States	SC-IND-coal	HC-IND	4.890	7.763	11.100
IRN	Iran	Middle Eastern States	SC-IND-gas	NG-IND	2.234	4.965	8.193
IRN	Iran	Middle Eastern States	SC-IND-oil	CO-HF-IND	50.659	112.575	185.749
IRN	Iran	Middle Eastern States	SC-IND-oil	CO-LF-IND	2.224	4.942	8.154
IRN	Iran	Middle Eastern States	SC-PP-gas	NG-PP	4.741	10.535	17.382
IRN	Iran	Middle Eastern States	SC-PP-oil	CO-HF-PP	81.011	180.025	297.041
IRN	Iran	Middle Eastern States	SC-PP-oil	CO-LF-PP	3.650	8.111	13.383
IRN	Iran	Middle Eastern States	WASOTH	WASOTH	319.511	1271.172	4225.788
IRN	Iran	Middle Eastern States	WI	WI	0.993	3.950	13.132
IRQ	Iraq	Middle Eastern States	CEM	CEM	201.600	556.800	2025.920
IRQ	Iraq	Middle Eastern States	CREM	CREM	0.434	1.931	6.879
IRQ	Iraq	Middle Eastern States	CSP	CSP-C	119.000	340.000	663.000
IRQ	Iraq	Middle Eastern States	OR	CO-OR	3.737	8.304	13.702
IRQ	Iraq	Middle Eastern States	SC-DR-oil	CO-LF-DR	5.171	11.492	18.962
IRQ	Iraq	Middle Eastern States	SC-IND-gas	NG-IND	0.098	0.218	0.360
IRQ	Iraq	Middle Eastern States	SC-IND-oil	CO-HF-IND	24.376	54.169	89.379
IRQ	Iraq	Middle Eastern States	SC-IND-oil	CO-LF-IND	2.456	5.459	9.007
IRQ	Iraq	Middle Eastern States	SC-PP-oil	CO-HF-PP	66.852	148.561	245.126
IRQ	Iraq	Middle Eastern States	SC-PP-oil	CO-PP	14.702	32.671	53.906
IRQ	Iraq	Middle Eastern States	WASOTH	WASOTH	42.758	170.113	565.511
IRQ	Iraq	Middle Eastern States	WI	WI	0.133	0.529	1.757
ISL	Iceland	CIS & other European countries	CEM	CEM	1.620	4.376	15.563
ISL	Iceland	CIS & other European countries	CREM	CREM	0.006	0.018	0.061
ISL	Iceland	CIS & other European countries	NFMP-AL	AL-P	3.413	9.750	19.013
ISL	Iceland	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.637	1.340	2.211
ISL	Iceland	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.202	0.426	0.703
ISL	Iceland	CIS & other European countries	SC-IND-coal	HC-IND	2.537	3.816	5.456
ISL	Iceland	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.199	0.418	0.690
ISL	Iceland	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.066	0.139	0.229
ISL	Iceland	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.002	0.004	0.006
ISL	Iceland	CIS & other European countries	WASOTH	WASOTH	0.839	3.243	11.070
ISL	Iceland	CIS & other European countries	WI	WI	0.304	1.177	4.018
ISR	Israel	Middle Eastern States	CEM	CEM	102.767	293.621	572.561
ISR	Israel	Middle Eastern States	CSP	CSP-C	28.875	82.500	160.875
ISR	Israel	Middle Eastern States	OR	CO-OR	18.120	38.148	62.944
ISR	Israel	Middle Eastern States	SC-DR-oil	CO-HF-DR	8.465	17.820	29.403
ISR	Israel	Middle Eastern States	SC-DR-oil	CO-LF-DR	2.635	5.548	9.154
ISR	Israel	Middle Eastern States	SC-IND-gas	NG-IND	0.018	0.039	0.064
ISR	Israel	Middle Eastern States	SC-IND-oil	CO-LF-IND	0.048	0.101	0.166
ISR	Israel	Middle Eastern States	SC-PP-coal	BC-L-PP	24.625	37.030	52.952
ISR	Israel	Middle Eastern States	SC-PP-coal	HC-B-PP	443.930	667.564	954.616

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
ISR	Israel	Middle Eastern States	SC-PP-gas	NG-PP	0.380	0.799	1.319
ISR	Israel	Middle Eastern States	SC-PP-oil	CO-HF-PP	8.080	17.010	28.067
ISR	Israel	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.174	0.365	0.603
ISR	Israel	Middle Eastern States	WASOTH	WASOTH	53.269	211.931	704.527
ISR	Israel	Middle Eastern States	WI	WI	1.535	6.106	20.297
ITA	Italy	EU27	CEM	CEM	626.574	1698.873	6720.595
ITA	Italy	EU27	CREM	CREM	3.736	13.837	45.661
ITA	Italy	EU27	CSP	CSP-C	146.983	419.950	818.902
ITA	Italy	EU27	NFMP-AL	AL-P	0.735	2.100	4.095
ITA	Italy	EU27	NFMP-AU	GP-L	0.009	1.238	3.218
ITA	Italy	EU27	NFMP-PB	PB-P	1.181	3.375	6.581
ITA	Italy	EU27	NFMP-ZN	ZN-T	83.160	221.400	544.050
ITA	Italy	EU27	OR	CO-OR	129.762	273.183	450.752
ITA	Italy	EU27	PISP	PIP	92.163	219.436	1568.966
ITA	Italy	EU27	SC-DR-coal	HC-DR	0.524	0.787	1.126
ITA	Italy	EU27	SC-DR-gas	NG-DR	2.892	6.088	10.045
ITA	Italy	EU27	SC-DR-oil	CO-HF-DR	7.021	14.780	24.387
ITA	Italy	EU27	SC-DR-oil	CO-LF-DR	26.040	54.820	90.453
ITA	Italy	EU27	SC-IND-coal	BC-IND	0.681	1.024	1.464
ITA	Italy	EU27	SC-IND-coal	HC-IND	18.361	27.611	39.484
ITA	Italy	EU27	SC-IND-gas	NG-IND	1.093	2.302	3.798
ITA	Italy	EU27	SC-IND-oil	CO-HF-IND	14.332	30.172	49.784
ITA	Italy	EU27	SC-IND-oil	CO-LF-IND	0.289	0.608	1.003
ITA	Italy	EU27	SC-PP-coal	BC-S-PP	41.944	63.074	90.196
ITA	Italy	EU27	SC-PP-coal	HC-B-PP	504.127	758.086	1084.063
ITA	Italy	EU27	SC-PP-gas	NG-PP	2.971	6.255	10.321
ITA	Italy	EU27	SC-PP-oil	CO-HF-PP	46.307	97.488	160.855
ITA	Italy	EU27	SC-PP-oil	CO-LF-PP	0.178	0.374	0.618
ITA	Italy	EU27	WASOTH	WASOTH	104.120	499.491	1937.319
ITA	Italy	EU27	WI	WI	37.789	181.281	703.115
JAM	Jamaica	Central America and the Caribbean	CEM	CEM	17.640	48.720	177.268
JAM	Jamaica	Central America and the Caribbean	CREM	CREM	0.471	1.905	6.388
JAM	Jamaica	Central America and the Caribbean	OR	CO-OR	0.536	1.190	1.964
JAM	Jamaica	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	7.263	16.140	26.631
JAM	Jamaica	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.212	0.470	0.776
JAM	Jamaica	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	0.180	0.399	0.658
JAM	Jamaica	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.015	0.034	0.056
JAM	Jamaica	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	6.276	13.946	23.011
JAM	Jamaica	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.203	0.450	0.743
JAM	Jamaica	Central America and the Caribbean	WASOTH	WASOTH	11.479	44.151	145.697
JAM	Jamaica	Central America and the Caribbean	WI	WI	0.036	0.137	0.453
JOR	Jordan	Middle Eastern States	CEM	CEM	126.000	348.000	1266.200
JOR	Jordan	Middle Eastern States	CREM	CREM	0.151	0.669	2.384
JOR	Jordan	Middle Eastern States	OR	CO-OR	0.644	1.430	2.360
JOR	Jordan	Middle Eastern States	SC-DR-oil	CO-HF-DR	0.072	0.160	0.264
JOR	Jordan	Middle Eastern States	SC-DR-oil	CO-LF-DR	0.932	2.070	3.416
JOR	Jordan	Middle Eastern States	SC-IND-oil	CO-HF-IND	2.480	5.510	9.092
JOR	Jordan	Middle Eastern States	SC-IND-oil	CO-LF-IND	0.465	1.034	1.705
JOR	Jordan	Middle Eastern States	SC-PP-gas	NG-PP	0.323	0.718	1.184
JOR	Jordan	Middle Eastern States	SC-PP-oil	CO-HF-PP	4.258	9.462	15.612
JOR	Jordan	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.015	0.032	0.053
JOR	Jordan	Middle Eastern States	WASOTH	WASOTH	13.030	51.839	172.328
JOR	Jordan	Middle Eastern States	WI	WI	0.040	0.161	0.536

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
JPN	Japan	East and Southeast Asia	CEM	CEM	962.299	2749.426	5361.380
JPN	Japan	East and Southeast Asia	CREM	CREM	11.080	39.911	126.883
JPN	Japan	East and Southeast Asia	NFMP-AL	AL-P	0.026	0.075	0.146
JPN	Japan	East and Southeast Asia	NFMP-AU	GP-L	0.135	19.250	50.050
JPN	Japan	East and Southeast Asia	NFMP-CU	CU-P	1443.591	2983.374	12636.122
JPN	Japan	East and Southeast Asia	NFMP-PB	PB-P	23.085	48.600	80.190
JPN	Japan	East and Southeast Asia	NFMP-ZN	ZN-P	647.816	1270.836	2642.409
JPN	Japan	East and Southeast Asia	OR	CO-OR	270.711	569.918	940.365
JPN	Japan	East and Southeast Asia	PISP	PIP	3130.630	4670.219	6328.542
JPN	Japan	East and Southeast Asia	SC-DR-coal	HC-DR	20.553	30.906	44.196
JPN	Japan	East and Southeast Asia	SC-DR-gas	NG-DR	2.710	5.705	9.413
JPN	Japan	East and Southeast Asia	SC-DR-oil	CO-HF-DR	23.817	50.140	82.731
JPN	Japan	East and Southeast Asia	SC-DR-oil	CO-LF-DR	31.377	66.056	108.992
JPN	Japan	East and Southeast Asia	SC-IND-coal	HC-IND	139.524	209.810	300.028
JPN	Japan	East and Southeast Asia	SC-IND-gas	NG-IND	0.818	1.722	2.842
JPN	Japan	East and Southeast Asia	SC-IND-oil	CO-HF-IND	35.179	74.062	122.202
JPN	Japan	East and Southeast Asia	SC-IND-oil	CO-IND	0.081	0.171	0.282
JPN	Japan	East and Southeast Asia	SC-IND-oil	CO-LF-IND	6.423	13.522	22.312
JPN	Japan	East and Southeast Asia	SC-PP-coal	HC-B-PP	586.714	882.277	1261.656
JPN	Japan	East and Southeast Asia	SC-PP-gas	NG-PP	6.096	12.834	21.175
JPN	Japan	East and Southeast Asia	SC-PP-oil	CO-HF-PP	85.526	180.054	297.089
JPN	Japan	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.493	1.039	1.714
JPN	Japan	East and Southeast Asia	SC-PP-oil	CO-PP	13.329	28.062	46.302
JPN	Japan	East and Southeast Asia	WASOTH	WASOTH	566.424	2242.094	7726.760
JPN	Japan	East and Southeast Asia	WI	WI	272.418	1078.323	3716.143
KAZ	Kazakhstan	CIS & other European countries	CEM	CEM	137.813	380.625	1384.906
KAZ	Kazakhstan	CIS & other European countries	CREM	CREM	2.838	9.459	31.214
KAZ	Kazakhstan	CIS & other European countries	NFMP-AL	AL-P	28.602	72.640	150.501
KAZ	Kazakhstan	CIS & other European countries	NFMP-AU	GP-L	7.623	1089.000	2831.400
KAZ	Kazakhstan	CIS & other European countries	NFMP-CU	CU-T	1689.282	4737.960	23716.368
KAZ	Kazakhstan	CIS & other European countries	NFMP-PB	PB-T	64.803	182.237	395.793
KAZ	Kazakhstan	CIS & other European countries	NFMP-ZN	ZN-T	1817.728	4839.405	11891.954
KAZ	Kazakhstan	CIS & other European countries	OR	CO-OR	18.085	40.188	66.310
KAZ	Kazakhstan	CIS & other European countries	PISP	PIP	10.524	25.056	179.150
KAZ	Kazakhstan	CIS & other European countries	SC-DR-coal	BC-DR	46.022	73.050	104.462
KAZ	Kazakhstan	CIS & other European countries	SC-DR-coal	HC-DR	190.418	302.250	432.218
KAZ	Kazakhstan	CIS & other European countries	SC-DR-gas	NG-DR	0.804	1.787	2.949
KAZ	Kazakhstan	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.576	1.280	2.112
KAZ	Kazakhstan	CIS & other European countries	SC-DR-oil	CO-LF-DR	1.455	3.234	5.336
KAZ	Kazakhstan	CIS & other European countries	SC-IND-coal	BC-IND	185.657	294.694	421.412
KAZ	Kazakhstan	CIS & other European countries	SC-IND-coal	HC-IND	318.264	505.181	722.409
KAZ	Kazakhstan	CIS & other European countries	SC-IND-oil	CO-HF-IND	5.004	11.120	18.348
KAZ	Kazakhstan	CIS & other European countries	SC-IND-oil	CO-LF-IND	1.077	2.394	3.950
KAZ	Kazakhstan	CIS & other European countries	SC-PP-coal	BC-L-PP	110.947	176.106	251.832
KAZ	Kazakhstan	CIS & other European countries	SC-PP-coal	HC-B-PP	3490.877	5541.075	7923.737
KAZ	Kazakhstan	CIS & other European countries	SC-PP-gas	NG-PP	1.188	2.639	4.355
KAZ	Kazakhstan	CIS & other European countries	SC-PP-oil	CO-HF-PP	4.158	9.240	15.246
KAZ	Kazakhstan	CIS & other European countries	SC-PP-oil	CO-PP	4.064	9.030	14.900
KAZ	Kazakhstan	CIS & other European countries	WASOTH	WASOTH	91.999	355.731	1214.392
KAZ	Kazakhstan	CIS & other European countries	WI	WI	0.286	1.105	3.774
KEN	Kenya	Sub-Saharan Africa	ASGM	ASGM	1406.250	5625.000	9843.750
KEN	Kenya	Sub-Saharan Africa	CEM	CEM	104.580	288.840	1050.946
KEN	Kenya	Sub-Saharan Africa	CREM	CREM	1.115	4.462	15.616

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
KEN	Kenya	Sub-Saharan Africa	NFMP-AU	GP-L	0.116	16.500	42.900
KEN	Kenya	Sub-Saharan Africa	OR	CO-OR	0.506	1.124	1.855
KEN	Kenya	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.090	0.200	0.330
KEN	Kenya	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.832	1.848	3.049
KEN	Kenya	Sub-Saharan Africa	SC-IND-coal	HC-IND	8.416	13.359	19.104
KEN	Kenya	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.522	1.160	1.914
KEN	Kenya	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.180	0.400	0.660
KEN	Kenya	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	5.949	13.220	21.813
KEN	Kenya	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.284	0.632	1.043
KEN	Kenya	Sub-Saharan Africa	WASOTH	WASOTH	37.968	154.073	511.742
KEN	Kenya	Sub-Saharan Africa	WI	WI	0.118	0.479	1.590
KGZ	Kyrgystan	CIS & other European countries	ASGM	ASGM	937.500	3750.000	6562.500
KGZ	Kyrgystan	CIS & other European countries	CEM	CEM	30.319	83.738	304.679
KGZ	Kyrgystan	CIS & other European countries	CREM	CREM	0.362	1.207	3.982
KGZ	Kyrgystan	CIS & other European countries	NFMP-AU	GP-L	5.873	839.025	2181.465
KGZ	Kyrgystan	CIS & other European countries	NFMP-HG	HG-P	984.375	1687.500	2559.375
KGZ	Kyrgystan	CIS & other European countries	OR	CO-OR	0.047	0.105	0.174
KGZ	Kyrgystan	CIS & other European countries	SC-DR-gas	NG-DR	0.030	0.067	0.111
KGZ	Kyrgystan	CIS & other European countries	SC-DR-oil	CO-HF-DR	2.250	5.000	8.250
KGZ	Kyrgystan	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.495	1.100	1.815
KGZ	Kyrgystan	CIS & other European countries	SC-IND-coal	BC-IND	55.467	88.043	125.901
KGZ	Kyrgystan	CIS & other European countries	SC-IND-coal	HC-IND	48.290	76.650	109.610
KGZ	Kyrgystan	CIS & other European countries	SC-PP-coal	HC-B-PP	21.404	33.975	48.584
KGZ	Kyrgystan	CIS & other European countries	SC-PP-gas	NG-PP	0.027	0.061	0.100
KGZ	Kyrgystan	CIS & other European countries	WASOTH	WASOTH	5.665	21.906	74.782
KGZ	Kyrgystan	CIS & other European countries	WI	WI	0.018	0.068	0.232
KHM	Cambodia	East and Southeast Asia	ASGM	ASGM	1875.000	3750.000	5625.000
KHM	Cambodia	East and Southeast Asia	CEM	CEM	21.333	58.921	214.383
KHM	Cambodia	East and Southeast Asia	CREM	CREM	4.337	15.624	49.671
KHM	Cambodia	East and Southeast Asia	SC-DR-oil	CO-HF-DR	0.027	0.060	0.099
KHM	Cambodia	East and Southeast Asia	SC-DR-oil	CO-LF-DR	0.286	0.636	1.049
KHM	Cambodia	East and Southeast Asia	SC-IND-oil	CO-HF-IND	0.243	0.540	0.891
KHM	Cambodia	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.024	0.054	0.089
KHM	Cambodia	East and Southeast Asia	SC-PP-oil	CO-HF-PP	2.034	4.520	7.458
KHM	Cambodia	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.196	0.436	0.719
KHM	Cambodia	East and Southeast Asia	WASOTH	WASOTH	26.211	103.750	357.547
KHM	Cambodia	East and Southeast Asia	WI	WI	0.081	0.322	1.111
KIR	Kiribati	Australia, New Zealand & Oceania	CREM	CREM	0.096	0.426	1.598
KIR	Kiribati	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.137	0.495	1.713
KIR	Kiribati	Australia, New Zealand & Oceania	WI	WI	0.000	0.002	0.005
KNA	Saint Kitts	Central America and the Caribbean	CREM	CREM	0.007	0.028	0.095
KNA	Saint Kitts	Central America and the Caribbean	WASOTH	WASOTH	0.370	1.424	4.698
KNA	Saint Kitts	Central America and the Caribbean	WI	WI	0.001	0.004	0.015
KOR	Korea- Rep. of	East and Southeast Asia	CEM	CEM	1615.820	2490.549	3452.346
KOR	Korea- Rep. of	East and Southeast Asia	CREM	CREM	2.732	9.841	31.285
KOR	Korea- Rep. of	East and Southeast Asia	NFMP-CU	CU-P	48.720	100.686	426.456
KOR	Korea- Rep. of	East and Southeast Asia	NFMP-PB	PB-P	28.494	59.987	98.979
KOR	Korea- Rep. of	East and Southeast Asia	NFMP-ZN	ZN-P	51.127	100.297	208.543
KOR	Korea- Rep. of	East and Southeast Asia	OR	CO-OR	177.720	374.146	617.342
KOR	Korea- Rep. of	East and Southeast Asia	PISP	PIP	461.778	494.610	553.451
KOR	Korea- Rep. of	East and Southeast Asia	SC-DR-coal	HC-DR	56.867	85.514	122.285
KOR	Korea- Rep. of	East and Southeast Asia	SC-DR-gas	NG-DR	1.380	2.905	4.794
KOR	Korea- Rep. of	East and Southeast Asia	SC-DR-oil	CO-HF-DR	43.433	91.439	150.874

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
KOR	Korea- Rep. of	East and Southeast Asia	SC-IND-gas	NG-IND	0.622	1.310	2.162
KOR	Korea- Rep. of	East and Southeast Asia	SC-IND-oil	CO-HF-IND	542.565	1142.241	1884.698
KOR	Korea- Rep. of	East and Southeast Asia	SC-PP-coal	HC-A-PP	22.875	34.399	49.191
KOR	Korea- Rep. of	East and Southeast Asia	SC-PP-coal	HC-B-PP	724.522	1089.507	1557.995
KOR	Korea- Rep. of	East and Southeast Asia	SC-PP-gas	NG-PP	1.404	2.956	4.878
KOR	Korea- Rep. of	East and Southeast Asia	SC-PP-oil	CO-HF-PP	23.189	48.818	80.550
KOR	Korea- Rep. of	East and Southeast Asia	WASOTH	WASOTH	186.650	738.821	2546.145
KOR	Korea- Rep. of	East and Southeast Asia	WI	WI	89.768	355.332	1224.554
KWT	Kuwait	Middle Eastern States	CEM	CEM	42.714	117.972	429.242
KWT	Kuwait	Middle Eastern States	CREM	CREM	0.456	2.026	7.217
KWT	Kuwait	Middle Eastern States	OR	CO-OR	7.846	17.435	28.767
KWT	Kuwait	Middle Eastern States	SC-DR-oil	CO-LF-DR	1.170	2.600	4.290
KWT	Kuwait	Middle Eastern States	SC-IND-gas	NG-IND	0.284	0.630	1.040
KWT	Kuwait	Middle Eastern States	SC-IND-oil	CO-LF-IND	0.741	1.647	2.718
KWT	Kuwait	Middle Eastern States	SC-PP-gas	NG-PP	0.775	1.722	2.841
KWT	Kuwait	Middle Eastern States	SC-PP-oil	CO-HF-PP	69.733	154.962	255.687
KWT	Kuwait	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.777	1.726	2.848
KWT	Kuwait	Middle Eastern States	SC-PP-oil	CO-PP	11.300	25.110	41.432
KWT	Kuwait	Middle Eastern States	WASOTH	WASOTH	31.546	125.506	417.224
KWT	Kuwait	Middle Eastern States	WI	WI	0.909	3.616	12.020
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	ASGM	ASGM	487.500	975.000	1462.500
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	CEM	CEM	11.025	30.450	110.793
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	CREM	CREM	1.903	6.856	21.795
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	NFMP-AU	GP-L	1.733	247.500	643.500
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	WASOTH	WASOTH	13.595	53.812	185.449
LAO	Lao Peoples Dem. Rep.	East and Southeast Asia	WI	WI	0.042	0.167	0.576
LBN	Lebanon	Middle Eastern States	CEM	CEM	126.000	348.000	1266.200
LBN	Lebanon	Middle Eastern States	CREM	CREM	0.654	2.906	10.352
LBN	Lebanon	Middle Eastern States	SC-DR-oil	CO-LF-DR	0.709	1.576	2.600
LBN	Lebanon	Middle Eastern States	SC-IND-coal	HC-IND	14.175	22.500	32.175
LBN	Lebanon	Middle Eastern States	SC-IND-oil	CO-HF-IND	1.454	3.230	5.330
LBN	Lebanon	Middle Eastern States	SC-PP-gas	NG-PP	0.004	0.010	0.016
LBN	Lebanon	Middle Eastern States	SC-PP-oil	CO-HF-PP	10.499	23.332	38.498
LBN	Lebanon	Middle Eastern States	SC-PP-oil	CO-LF-PP	1.545	3.433	5.665
LBN	Lebanon	Middle Eastern States	WASOTH	WASOTH	22.265	88.581	294.472
LBN	Lebanon	Middle Eastern States	WI	WI	0.069	0.275	0.915
LBR	Liberia	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
LBR	Liberia	Sub-Saharan Africa	CEM	CEM	2.993	8.265	30.072
LBR	Liberia	Sub-Saharan Africa	CREM	CREM	0.071	0.285	0.997
LBR	Liberia	Sub-Saharan Africa	NFMP-AU	GP-L	0.231	33.000	85.800
LBR	Liberia	Sub-Saharan Africa	WASOTH	WASOTH	0.952	3.862	12.827
LBR	Liberia	Sub-Saharan Africa	WI	WI	0.003	0.012	0.040
LBY	Libyan Arab Jamah	North Africa	CEM	CEM	189.000	522.000	1899.300
LBY	Libyan Arab Jamah	North Africa	CREM	CREM	0.055	0.227	0.818
LBY	Libyan Arab Jamah	North Africa	CSP	CSP-C	315.000	900.000	1755.000
LBY	Libyan Arab Jamah	North Africa	OR	CO-OR	3.465	7.700	12.706
LBY	Libyan Arab Jamah	North Africa	SC-DR-oil	CO-LF-DR	2.285	5.078	8.379
LBY	Libyan Arab Jamah	North Africa	SC-IND-gas	NG-IND	0.106	0.235	0.387
LBY	Libyan Arab Jamah	North Africa	SC-IND-oil	CO-HF-IND	3.807	8.460	13.959
LBY	Libyan Arab Jamah	North Africa	SC-PP-gas	NG-PP	0.330	0.733	1.209
LBY	Libyan Arab Jamah	North Africa	SC-PP-oil	CO-HF-PP	27.324	60.720	100.188
LBY	Libyan Arab Jamah	North Africa	SC-PP-oil	CO-LF-PP	3.055	6.788	11.200
LBY	Libyan Arab Jamah	North Africa	WASOTH	WASOTH	56.742	218.240	698.369

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
LBY	Libyan Arab Jamah	North Africa	WI	WI	0.176	0.678	2.170
LCA	Saint Lucia	Central America and the Caribbean	CREM	CREM	0.030	0.122	0.409
LCA	Saint Lucia	Central America and the Caribbean	WASOTH	WASOTH	0.872	3.356	11.074
LCA	Saint Lucia	Central America and the Caribbean	WI	WI	0.003	0.010	0.034
LKA	Sri Lanka	South Asia	CEM	CEM	59.850	165.300	601.445
LKA	Sri Lanka	South Asia	CREM	CREM	2.757	11.609	40.632
LKA	Sri Lanka	South Asia	OR	CO-OR	12.272	27.271	44.997
LKA	Sri Lanka	South Asia	SC-DR-oil	CO-HF-DR	0.306	0.680	1.122
LKA	Sri Lanka	South Asia	SC-DR-oil	CO-LF-DR	1.014	2.254	3.719
LKA	Sri Lanka	South Asia	SC-IND-coal	HC-IND	6.645	10.547	15.082
LKA	Sri Lanka	South Asia	SC-IND-oil	CO-HF-IND	1.818	4.040	6.666
LKA	Sri Lanka	South Asia	SC-IND-oil	CO-LF-IND	0.069	0.154	0.254
LKA	Sri Lanka	South Asia	SC-PP-oil	CO-HF-PP	8.874	19.720	32.538
LKA	Sri Lanka	South Asia	SC-PP-oil	CO-LF-PP	0.283	0.628	1.036
LKA	Sri Lanka	South Asia	WASOTH	WASOTH	81.380	343.168	1215.797
LKA	Sri Lanka	South Asia	WI	WI	0.253	1.066	3.778
LSO	Lesotho	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
LSO	Lesotho	Sub-Saharan Africa	CREM	CREM	0.077	0.309	1.083
LSO	Lesotho	Sub-Saharan Africa	WASOTH	WASOTH	1.909	7.747	25.732
LSO	Lesotho	Sub-Saharan Africa	WI	WI	0.006	0.024	0.080
LTU	Lithuania	EU27	CEM	CEM	17.429	48.137	175.147
LTU	Lithuania	EU27	CREM	CREM	0.873	3.232	10.666
LTU	Lithuania	EU27	OR	CO-OR	12.863	28.584	47.163
LTU	Lithuania	EU27	SC-DR-coal	HC-DR	2.811	4.463	6.381
LTU	Lithuania	EU27	SC-DR-gas	NG-DR	0.027	0.060	0.099
LTU	Lithuania	EU27	SC-DR-oil	CO-HF-DR	0.018	0.040	0.066
LTU	Lithuania	EU27	SC-DR-oil	CO-LF-DR	0.766	1.702	2.808
LTU	Lithuania	EU27	SC-IND-coal	HC-IND	3.402	5.400	7.722
LTU	Lithuania	EU27	SC-IND-gas	NG-IND	0.027	0.061	0.101
LTU	Lithuania	EU27	SC-IND-oil	CO-HF-IND	0.077	0.171	0.282
LTU	Lithuania	EU27	SC-IND-oil	CO-LF-IND	0.015	0.034	0.056
LTU	Lithuania	EU27	SC-PP-coal	HC-A-PP	0.064	0.102	0.145
LTU	Lithuania	EU27	SC-PP-coal	HC-B-PP	0.065	0.104	0.148
LTU	Lithuania	EU27	SC-PP-gas	NG-PP	0.113	0.252	0.415
LTU	Lithuania	EU27	SC-PP-oil	CO-HF-PP	2.827	6.282	10.365
LTU	Lithuania	EU27	SC-PP-oil	CO-LF-PP	0.004	0.009	0.015
LTU	Lithuania	EU27	WASOTH	WASOTH	3.294	15.803	61.293
LTU	Lithuania	EU27	WI	WI	1.196	5.735	22.245
LUX	Luxembourg	EU27	CEM	CEM	21.559	58.851	394.773
LUX	Luxembourg	EU27	CREM	CREM	0.127	0.470	1.552
LUX	Luxembourg	EU27	SC-DR-gas	NG-DR	0.043	0.091	0.150
LUX	Luxembourg	EU27	SC-DR-oil	CO-LF-DR	1.762	3.710	6.122
LUX	Luxembourg	EU27	SC-IND-coal	HC-IND	4.798	7.215	10.317
LUX	Luxembourg	EU27	SC-IND-gas	NG-IND	0.027	0.056	0.093
LUX	Luxembourg	EU27	SC-IND-oil	CO-HF-IND	0.027	0.057	0.094
LUX	Luxembourg	EU27	SC-PP-gas	NG-PP	0.053	0.112	0.184
LUX	Luxembourg	EU27	SC-PP-oil	CO-LF-PP	0.001	0.002	0.003
LUX	Luxembourg	EU27	WASOTH	WASOTH	2.477	11.884	46.092
LUX	Luxembourg	EU27	WI	WI	0.899	4.313	16.728
LVA	Latvia	EU27	CEM	CEM	4.753	13.128	47.767
LVA	Latvia	EU27	CREM	CREM	0.589	2.182	7.200
LVA	Latvia	EU27	SC-DR-coal	HC-DR	4.631	7.350	10.511
LVA	Latvia	EU27	SC-DR-gas	NG-DR	0.023	0.051	0.084

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
LVA	Latvia	EU27	SC-DR-oil	CO-HF-DR	0.009	0.020	0.033
LVA	Latvia	EU27	SC-DR-oil	CO-LF-DR	0.617	1.372	2.264
LVA	Latvia	EU27	SC-IND-coal	HC-IND	2.764	4.388	6.274
LVA	Latvia	EU27	SC-IND-gas	NG-IND	0.022	0.049	0.081
LVA	Latvia	EU27	SC-IND-oil	CO-HF-IND	0.068	0.152	0.251
LVA	Latvia	EU27	SC-IND-oil	CO-LF-IND	0.031	0.068	0.113
LVA	Latvia	EU27	SC-PP-coal	HC-B-PP	0.717	1.139	1.628
LVA	Latvia	EU27	SC-PP-gas	NG-PP	0.082	0.181	0.299
LVA	Latvia	EU27	SC-PP-oil	CO-HF-PP	0.211	0.468	0.772
LVA	Latvia	EU27	SC-PP-oil	CO-LF-PP	0.003	0.007	0.012
LVA	Latvia	EU27	WASOTH	WASOTH	1.996	9.575	37.137
LVA	Latvia	EU27	WI	WI	0.724	3.475	13.478
MAR	Morocco	North Africa	CEM	CEM	382.200	1092.000	2129.400
MAR	Morocco	North Africa	CREM	CREM	0.036	0.152	0.547
MAR	Morocco	North Africa	CSP	CSP-C	56.000	160.000	312.000
MAR	Morocco	North Africa	NFMP-AU	GP-L	0.462	66.000	171.600
MAR	Morocco	North Africa	NFMP-HG	HG-P	39.375	67.500	102.375
MAR	Morocco	North Africa	NFMP-PB	PB-P	43.505	122.344	265.714
MAR	Morocco	North Africa	OR	CO-OR	6.895	15.322	25.281
MAR	Morocco	North Africa	PISP	PIP	0.315	0.750	5.363
MAR	Morocco	North Africa	SC-DR-oil	CO-LF-DR	3.776	8.392	13.847
MAR	Morocco	North Africa	SC-IND-coal	HC-IND	2.038	3.234	4.625
MAR	Morocco	North Africa	SC-IND-gas	NG-IND	0.004	0.009	0.014
MAR	Morocco	North Africa	SC-IND-oil	CO-HF-IND	8.091	17.980	29.667
MAR	Morocco	North Africa	SC-IND-oil	CO-LF-IND	0.116	0.258	0.426
MAR	Morocco	North Africa	SC-PP-coal	HC-B-PP	288.887	458.550	655.727
MAR	Morocco	North Africa	SC-PP-gas	NG-PP	0.051	0.114	0.188
MAR	Morocco	North Africa	SC-PP-oil	CO-HF-PP	7.956	17.680	29.172
MAR	Morocco	North Africa	SC-PP-oil	CO-LF-PP	0.095	0.210	0.347
MAR	Morocco	North Africa	WASOTH	WASOTH	81.601	313.849	1004.317
MAR	Morocco	North Africa	WI	WI	0.254	0.975	3.121
MCO	Monaco	EU27	CREM	CREM	0.008	0.031	0.103
MCO	Monaco	EU27	WASOTH	WASOTH	0.053	0.256	0.991
MCO	Monaco	EU27	WI	WI	0.019	0.093	0.360
MDA	Republic of Moldova	CIS & other European countries	CEM	CEM	19.294	53.288	193.887
MDA	Republic of Moldova	CIS & other European countries	CREM	CREM	0.380	1.268	4.185
MDA	Republic of Moldova	CIS & other European countries	SC-DR-coal	HC-DR	10.868	17.250	24.668
MDA	Republic of Moldova	CIS & other European countries	SC-DR-gas	NG-DR	0.037	0.083	0.136
MDA	Republic of Moldova	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.099	0.220	0.363
MDA	Republic of Moldova	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.301	0.668	1.102
MDA	Republic of Moldova	CIS & other European countries	SC-IND-coal	HC-IND	4.713	7.481	10.698
MDA	Republic of Moldova	CIS & other European countries	SC-IND-gas	NG-IND	0.004	0.010	0.016
MDA	Republic of Moldova	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.009	0.020	0.033
MDA	Republic of Moldova	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.002	0.004	0.007
MDA	Republic of Moldova	CIS & other European countries	SC-PP-coal	HC-A-PP	0.284	0.450	0.644
MDA	Republic of Moldova	CIS & other European countries	SC-PP-gas	NG-PP	0.109	0.242	0.400
MDA	Republic of Moldova	CIS & other European countries	SC-PP-oil	CO-HF-PP	0.225	0.500	0.825
MDA	Republic of Moldova	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.002	0.004	0.007
MDA	Republic of Moldova	CIS & other European countries	SC-PP-oil	CO-PP	0.077	0.170	0.281
MDA	Republic of Moldova	CIS & other European countries	WASOTH	WASOTH	5.145	19.894	67.913
MDA	Republic of Moldova	CIS & other European countries	WI	WI	0.016	0.062	0.211
MDG	Madagascar	Sub-Saharan Africa	ASGM	ASGM	281.250	1125.000	1968.750
MDG	Madagascar	Sub-Saharan Africa	CEM	CEM	7.560	20.880	75.972

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
MDG	Madagascar	Sub-Saharan Africa	CREM	CREM	0.594	2.378	8.321
MDG	Madagascar	Sub-Saharan Africa	NFMP-AU	GP-L	0.027	3.850	10.010
MDG	Madagascar	Sub-Saharan Africa	WASOTH	WASOTH	11.418	46.335	153.897
MDG	Madagascar	Sub-Saharan Africa	WI	WI	0.035	0.144	0.478
MDV	Maldives	South Asia	CREM	CREM	0.000	0.001	0.003
MDV	Maldives	South Asia	WASOTH	WASOTH	1.389	5.859	20.757
MDV	Maldives	South Asia	WI	WI	0.004	0.018	0.065
MEX	Mexico	Central America and the Caribbean	ASGM	ASGM	937.500	3750.000	6562.500
MEX	Mexico	Central America and the Caribbean	CEM	CEM	1048.800	2070.000	6572.940
MEX	Mexico	Central America and the Caribbean	CREM	CREM	28.061	113.581	380.830
MEX	Mexico	Central America and the Caribbean	CSP	CSP-C	210.000	600.000	1170.000
MEX	Mexico	Central America and the Caribbean	NFMP-AU	GP-L	27.311	2874.802	6324.564
MEX	Mexico	Central America and the Caribbean	NFMP-CU	CU-P	1045.688	2161.054	9153.174
MEX	Mexico	Central America and the Caribbean	NFMP-PB	PB-P	100.763	210.116	370.359
MEX	Mexico	Central America and the Caribbean	NFMP-ZN	ZN-P	2762.962	5420.165	11269.977
MEX	Mexico	Central America and the Caribbean	OR	CO-OR	33.222	69.941	115.403
MEX	Mexico	Central America and the Caribbean	PISP	PIP	145.873	312.585	791.882
MEX	Mexico	Central America and the Caribbean	SC-DR-gas	NG-DR	0.100	0.211	0.349
MEX	Mexico	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.977	2.057	3.394
MEX	Mexico	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	15.672	32.994	54.440
MEX	Mexico	Central America and the Caribbean	SC-IND-coal	BC-IND	41.101	61.807	88.384
MEX	Mexico	Central America and the Caribbean	SC-IND-gas	NG-IND	0.911	1.918	3.165
MEX	Mexico	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	28.477	59.953	98.922
MEX	Mexico	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	1.192	2.510	4.141
MEX	Mexico	Central America and the Caribbean	SC-PP-coal	BC-S-PP	2233.195	3358.187	4802.208
MEX	Mexico	Central America and the Caribbean	SC-PP-gas	NG-PP	4.075	8.578	14.154
MEX	Mexico	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	85.125	179.210	295.697
MEX	Mexico	Central America and the Caribbean	WASOTH	WASOTH	542.884	2088.014	6890.446
MEX	Mexico	Central America and the Caribbean	WI	WI	3.692	14.201	46.863
MHL	Marshall Islands	Australia, New Zealand & Oceania	CREM	CREM	0.055	0.245	0.917
MHL	Marshall Islands	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.075	0.271	0.937
MHL	Marshall Islands	Australia, New Zealand & Oceania	WI	WI	0.000	0.001	0.003
MKD	Macedonia	CIS & other European countries	CEM	CEM	25.054	69.198	251.776
MKD	Macedonia	CIS & other European countries	OR	CO-OR	1.487	3.305	5.453
MKD	Macedonia	CIS & other European countries	SC-DR-coal	BC-DR	0.945	1.500	2.145
MKD	Macedonia	CIS & other European countries	SC-DR-gas	NG-DR	0.000	0.000	0.000
MKD	Macedonia	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.072	0.160	0.264
MKD	Macedonia	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.306	0.680	1.122
MKD	Macedonia	CIS & other European countries	SC-IND-coal	BC-IND	10.780	17.111	24.469
MKD	Macedonia	CIS & other European countries	SC-IND-coal	HC-IND	0.473	0.750	1.073
MKD	Macedonia	CIS & other European countries	SC-IND-gas	NG-IND	0.003	0.007	0.011
MKD	Macedonia	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.738	1.640	2.706
MKD	Macedonia	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.023	0.050	0.083
MKD	Macedonia	CIS & other European countries	SC-PP-coal	BC-L-PP	449.499	713.491	1020.292
MKD	Macedonia	CIS & other European countries	SC-PP-gas	NG-PP	0.004	0.008	0.013
MKD	Macedonia	CIS & other European countries	SC-PP-oil	CO-HF-PP	1.377	3.060	5.049
MKD	Macedonia	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.008	0.018	0.030
MKD	Macedonia	CIS & other European countries	WASOTH	WASOTH	6.920	26.756	91.340
MKD	Macedonia	CIS & other European countries	WI	WI	0.199	0.771	2.631
MLI	Mali	Sub-Saharan Africa	ASGM	ASGM	10500.000	15000.000	19500.000
MLI	Mali	Sub-Saharan Africa	CREM	CREM	0.092	0.367	1.283
MLI	Mali	Sub-Saharan Africa	NFMP-AU	GP-L	16.170	2310.000	6006.000
MLI	Mali	Sub-Saharan Africa	WASOTH	WASOTH	9.311	37.785	125.499

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MLI	Mali	Sub-Saharan Africa	WI	WI	0.029	0.117	0.390
MLT	Malta	EU27	CREM	CREM	0.104	0.386	1.274
MLT	Malta	EU27	SC-DR-oil	CO-LF-DR	0.069	0.154	0.254
MLT	Malta	EU27	SC-IND-oil	CO-LF-IND	0.022	0.049	0.082
MLT	Malta	EU27	SC-PP-oil	CO-HF-PP	4.236	9.414	15.533
MLT	Malta	EU27	SC-PP-oil	CO-LF-PP	0.062	0.139	0.229
MLT	Malta	EU27	WASOTH	WASOTH	0.559	2.683	10.405
MLT	Malta	EU27	WI	WI	0.203	0.974	3.776
MMR	Myanmar	East and Southeast Asia	CEM	CEM	21.105	58.290	212.089
MMR	Myanmar	East and Southeast Asia	CREM	CREM	14.562	52.456	166.763
MMR	Myanmar	East and Southeast Asia	CSP	CSP-C	49.000	140.000	273.000
MMR	Myanmar	East and Southeast Asia	NFMP-AU	GP-L	0.039	5.500	14.300
MMR	Myanmar	East and Southeast Asia	NFMP-PB	PB-P	0.193	0.544	1.181
MMR	Myanmar	East and Southeast Asia	OR	CO-OR	1.222	2.717	4.482
MMR	Myanmar	East and Southeast Asia	PISP	PIP	0.042	0.100	0.715
MMR	Myanmar	East and Southeast Asia	SC-DR-coal	BC-DR	8.316	13.200	18.876
MMR	Myanmar	East and Southeast Asia	SC-DR-gas	NG-DR	0.125	0.279	0.460
MMR	Myanmar	East and Southeast Asia	SC-DR-oil	CO-HF-DR	0.378	0.840	1.386
MMR	Myanmar	East and Southeast Asia	SC-DR-oil	CO-LF-DR	0.408	0.906	1.495
MMR	Myanmar	East and Southeast Asia	SC-IND-coal	BC-IND	2.706	4.296	6.143
MMR	Myanmar	East and Southeast Asia	SC-IND-coal	HC-IND	15.681	24.891	35.594
MMR	Myanmar	East and Southeast Asia	SC-IND-gas	NG-IND	0.060	0.133	0.219
MMR	Myanmar	East and Southeast Asia	SC-IND-oil	CO-HF-IND	0.702	1.560	2.574
MMR	Myanmar	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.078	0.174	0.287
MMR	Myanmar	East and Southeast Asia	SC-PP-gas	NG-PP	0.052	0.116	0.191
MMR	Myanmar	East and Southeast Asia	SC-PP-oil	CO-HF-PP	0.252	0.560	0.924
MMR	Myanmar	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.093	0.206	0.340
MMR	Myanmar	East and Southeast Asia	WASOTH	WASOTH	65.938	261.006	899.485
MMR	Myanmar	East and Southeast Asia	WI	WI	0.205	0.811	2.795
MNG	Mongolia	East and Southeast Asia	ASGM	ASGM	4025.000	5750.000	7475.000
MNG	Mongolia	East and Southeast Asia	CEM	CEM	3.528	9.744	35.454
MNG	Mongolia	East and Southeast Asia	CREM	CREM	0.437	1.576	5.009
MNG	Mongolia	East and Southeast Asia	NFMP-AU	GP-L	2.717	388.199	1009.317
MNG	Mongolia	East and Southeast Asia	SC-DR-coal	BC-DR	123.417	195.900	280.137
MNG	Mongolia	East and Southeast Asia	SC-DR-oil	CO-LF-DR	0.132	0.294	0.485
MNG	Mongolia	East and Southeast Asia	SC-IND-coal	BC-IND	18.153	28.815	41.205
MNG	Mongolia	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.190	0.422	0.696
MNG	Mongolia	East and Southeast Asia	SC-PP-coal	BC-L-PP	310.636	493.074	705.096
MNG	Mongolia	East and Southeast Asia	SC-PP-oil	CO-HF-PP	0.043	0.095	0.157
MNG	Mongolia	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.040	0.089	0.147
MNG	Mongolia	East and Southeast Asia	WASOTH	WASOTH	9.500	37.603	129.588
MNG	Mongolia	East and Southeast Asia	WI	WI	0.030	0.117	0.403
MNP	North Mariana Islands	Australia, New Zealand & Oceania	CREM	CREM	0.075	0.335	1.254
MNP	North Mariana Islands	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.505	1.825	6.318
MNP	North Mariana Islands	Australia, New Zealand & Oceania	WI	WI	0.002	0.006	0.020
MOZ	Mozambique	Sub-Saharan Africa	ASGM	ASGM	1500.000	3000.000	4500.000
MOZ	Mozambique	Sub-Saharan Africa	CEM	CEM	22.877	63.184	229.894
MOZ	Mozambique	Sub-Saharan Africa	CREM	CREM	0.476	1.906	6.669
MOZ	Mozambique	Sub-Saharan Africa	NFMP-AL	AL-P	46.788	72.410	97.754
MOZ	Mozambique	Sub-Saharan Africa	NFMP-AU	GP-L	0.177	25.295	65.766
MOZ	Mozambique	Sub-Saharan Africa	SC-DR-gas	NG-DR	0.002	0.005	0.008
MOZ	Mozambique	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.370	0.822	1.356
MOZ	Mozambique	Sub-Saharan Africa	SC-IND-coal	HC-IND	0.413	0.656	0.938

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
MOZ	Mozambique	Sub-Saharan Africa	SC-IND-gas	NG-IND	0.006	0.014	0.022
MOZ	Mozambique	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.089	0.198	0.327
MOZ	Mozambique	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	0.354	0.562	0.804
MOZ	Mozambique	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.000	0.001	0.001
MOZ	Mozambique	Sub-Saharan Africa	WASOTH	WASOTH	12.539	50.883	169.004
MOZ	Mozambique	Sub-Saharan Africa	WI	WI	0.039	0.158	0.525
MRT	Mauritania	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
MRT	Mauritania	Sub-Saharan Africa	CEM	CEM	15.750	43.500	158.275
MRT	Mauritania	Sub-Saharan Africa	CREM	CREM	0.000	0.001	0.003
MRT	Mauritania	Sub-Saharan Africa	NFMP-AU	GP-L	3.080	440.000	1144.000
MRT	Mauritania	Sub-Saharan Africa	WASOTH	WASOTH	3.827	15.532	51.588
MRT	Mauritania	Sub-Saharan Africa	WI	WI	0.012	0.048	0.160
MSR	Monserat	Central America and the Caribbean	CREM	CREM	0.002	0.007	0.023
MSR	Monserat	Central America and the Caribbean	WASOTH	WASOTH	0.016	0.060	0.199
MSR	Monserat	Central America and the Caribbean	WI	WI	0.000	0.000	0.001
MTQ	Martinique	Central America and the Caribbean	CEM	CEM	5.544	15.312	55.713
MTQ	Martinique	Central America and the Caribbean	CREM	CREM	0.069	0.279	0.935
MUS	Mauritius	Sub-Saharan Africa	CREM	CREM	0.031	0.125	0.438
MUS	Mauritius	Sub-Saharan Africa	WASOTH	WASOTH	9.972	40.467	134.409
MUS	Mauritius	Sub-Saharan Africa	WI	WI	0.031	0.126	0.418
MWI	Malawi	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
MWI	Malawi	Sub-Saharan Africa	CEM	CEM	6.615	18.270	66.476
MWI	Malawi	Sub-Saharan Africa	CREM	CREM	0.385	1.539	5.386
MWI	Malawi	Sub-Saharan Africa	WASOTH	WASOTH	7.480	30.354	100.818
MWI	Malawi	Sub-Saharan Africa	WI	WI	0.023	0.094	0.313
MYS	Malaysia	East and Southeast Asia	ASGM	ASGM	437.500	1750.000	3062.500
MYS	Malaysia	East and Southeast Asia	CEM	CEM	402.098	1110.555	4040.761
MYS	Malaysia	East and Southeast Asia	CREM	CREM	3.686	13.278	42.213
MYS	Malaysia	East and Southeast Asia	NFMP-AU	GP-L	0.527	75.298	195.776
MYS	Malaysia	East and Southeast Asia	OR	CO-OR	107.840	239.644	395.412
MYS	Malaysia	East and Southeast Asia	SC-DR-gas	NG-DR	0.025	0.055	0.091
MYS	Malaysia	East and Southeast Asia	SC-DR-oil	CO-HF-DR	0.855	1.900	3.135
MYS	Malaysia	East and Southeast Asia	SC-DR-oil	CO-LF-DR	4.940	10.978	18.114
MYS	Malaysia	East and Southeast Asia	SC-IND-coal	HC-IND	159.947	253.884	363.055
MYS	Malaysia	East and Southeast Asia	SC-IND-gas	NG-IND	0.428	0.951	1.570
MYS	Malaysia	East and Southeast Asia	SC-IND-oil	CO-HF-IND	10.311	22.914	37.808
MYS	Malaysia	East and Southeast Asia	SC-IND-oil	CO-LF-IND	2.580	5.734	9.461
MYS	Malaysia	East and Southeast Asia	SC-PP-coal	HC-B-PP	1060.354	1683.101	2406.835
MYS	Malaysia	East and Southeast Asia	SC-PP-gas	NG-PP	2.098	4.662	7.692
MYS	Malaysia	East and Southeast Asia	SC-PP-oil	CO-HF-PP	1.677	3.726	6.148
MYS	Malaysia	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.380	0.844	1.393
MYS	Malaysia	East and Southeast Asia	WASOTH	WASOTH	233.827	925.565	3189.703
MYS	Malaysia	East and Southeast Asia	WI	WI	6.736	26.665	91.894
NAM	Namibia	Sub-Saharan Africa	CREM	CREM	0.076	0.304	1.062
NAM	Namibia	Sub-Saharan Africa	NFMP-AU	GP-L	0.560	80.071	208.185
NAM	Namibia	Sub-Saharan Africa	NFMP-CU	CU-P	52.857	148.249	742.074
NAM	Namibia	Sub-Saharan Africa	NFMP-ZN	ZN-T	604.032	1608.136	3951.700
NAM	Namibia	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.171	0.380	0.627
NAM	Namibia	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.410	0.910	1.502
NAM	Namibia	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.017	0.038	0.063
NAM	Namibia	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.063	0.141	0.232
NAM	Namibia	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	12.311	19.541	27.944
NAM	Namibia	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.002	0.004	0.006

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
NAM	Namibia	Sub-Saharan Africa	WASOTH	WASOTH	5.452	22.125	73.486
NAM	Namibia	Sub-Saharan Africa	WI	WI	0.157	0.637	2.117
NCL	New Caledonia	Australia, New Zealand & Oceania	CEM	CEM	3.583	9.896	36.008
NCL	New Caledonia	Australia, New Zealand & Oceania	CREM	CREM	0.186	0.828	3.105
NCL	New Caledonia	Australia, New Zealand & Oceania	WASOTH	WASOTH	1.773	6.404	22.168
NCL	New Caledonia	Australia, New Zealand & Oceania	WI	WI	0.006	0.020	0.069
NER	Niger	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
NER	Niger	Sub-Saharan Africa	CEM	CEM	1.260	3.480	12.662
NER	Niger	Sub-Saharan Africa	CREM	CREM	0.053	0.211	0.738
NER	Niger	Sub-Saharan Africa	NFMP-AU	GP-L	0.770	110.000	286.000
NER	Niger	Sub-Saharan Africa	WASOTH	WASOTH	6.426	26.078	86.616
NER	Niger	Sub-Saharan Africa	WI	WI	0.020	0.081	0.269
NFK	Norfolk Islands	Australia, New Zealand & Oceania	CREM	CREM	0.002	0.008	0.031
NGA	Nigeria	Sub-Saharan Africa	ASGM	ASGM	7500.000	15000.000	22500.000
NGA	Nigeria	Sub-Saharan Africa	CEM	CEM	141.750	391.500	1424.475
NGA	Nigeria	Sub-Saharan Africa	CREM	CREM	5.498	21.990	76.965
NGA	Nigeria	Sub-Saharan Africa	NFMP-AL	AL-P	1.764	2.730	3.686
NGA	Nigeria	Sub-Saharan Africa	NFMP-AU	GP-L	0.077	11.000	28.600
NGA	Nigeria	Sub-Saharan Africa	OR	CO-OR	0.745	1.656	2.733
NGA	Nigeria	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.568	1.262	2.082
NGA	Nigeria	Sub-Saharan Africa	SC-IND-coal	HC-IND	0.709	1.125	1.609
NGA	Nigeria	Sub-Saharan Africa	SC-IND-gas	NG-IND	0.104	0.231	0.381
NGA	Nigeria	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	1.584	3.520	5.808
NGA	Nigeria	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.021	0.046	0.076
NGA	Nigeria	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.457	1.016	1.676
NGA	Nigeria	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	4.041	8.980	14.817
NGA	Nigeria	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.279	0.620	1.023
NGA	Nigeria	Sub-Saharan Africa	WASOTH	WASOTH	216.224	877.432	2914.329
NGA	Nigeria	Sub-Saharan Africa	WI	WI	0.672	2.727	9.056
NIC	Nicaragua	Central America and the Caribbean	ASGM	ASGM	375.000	750.000	1125.000
NIC	Nicaragua	Central America and the Caribbean	CEM	CEM	13.356	36.888	134.217
NIC	Nicaragua	Central America and the Caribbean	CREM	CREM	0.994	4.025	13.495
NIC	Nicaragua	Central America and the Caribbean	NFMP-AU	GP-L	0.942	134.640	350.064
NIC	Nicaragua	Central America and the Caribbean	OR	CO-OR	0.370	0.822	1.356
NIC	Nicaragua	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.009	0.020	0.033
NIC	Nicaragua	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.296	0.658	1.086
NIC	Nicaragua	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	0.385	0.855	1.411
NIC	Nicaragua	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.058	0.129	0.213
NIC	Nicaragua	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	4.557	10.127	16.710
NIC	Nicaragua	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.017	0.038	0.063
NIC	Nicaragua	Central America and the Caribbean	WASOTH	WASOTH	8.675	33.365	110.104
NIC	Nicaragua	Central America and the Caribbean	WI	WI	0.027	0.104	0.342
NIU	Niue	Australia, New Zealand & Oceania	CREM	CREM	0.001	0.006	0.022
NIU	Niue	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.006	0.020	0.070
NIU	Niue	Australia, New Zealand & Oceania	WI	WI	0.000	0.000	0.000
NLD	Netherlands	EU27	CEM	CEM	93.166	255.323	1944.731
NLD	Netherlands	EU27	CREM	CREM	4.818	17.843	58.882
NLD	Netherlands	EU27	NFMP-AL	AL-P	1.313	3.750	7.313
NLD	Netherlands	EU27	NFMP-ZN	ZN-P	186.278	495.936	1218.672
NLD	Netherlands	EU27	OR	CO-OR	78.205	164.642	271.659
NLD	Netherlands	EU27	PISP	PIP	62.473	148.744	1063.522
NLD	Netherlands	EU27	SC-DR-coal	BC-DR	0.584	0.878	1.255
NLD	Netherlands	EU27	SC-DR-coal	HC-DR	0.611	0.919	1.314

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
NLD	Netherlands	EU27	SC-DR-gas	NG-DR	1.578	3.321	5.480
NLD	Netherlands	EU27	SC-DR-oil	CO-HF-DR	0.618	1.300	2.145
NLD	Netherlands	EU27	SC-DR-oil	CO-LF-DR	6.793	14.300	23.595
NLD	Netherlands	EU27	SC-IND-coal	BC-IND	1.618	2.434	3.480
NLD	Netherlands	EU27	SC-IND-coal	HC-IND	1.661	2.498	3.571
NLD	Netherlands	EU27	SC-IND-gas	NG-IND	0.528	1.112	1.835
NLD	Netherlands	EU27	SC-IND-oil	CO-LF-IND	0.118	0.249	0.411
NLD	Netherlands	EU27	SC-PP-coal	HC-B-PP	289.248	434.959	621.991
NLD	Netherlands	EU27	SC-PP-gas	NG-PP	1.552	3.268	5.392
NLD	Netherlands	EU27	SC-PP-oil	CO-HF-PP	0.547	1.152	1.901
NLD	Netherlands	EU27	SC-PP-oil	CO-LF-PP	0.010	0.022	0.036
NLD	Netherlands	EU27	WASOTH	WASOTH	38.294	183.706	712.521
NLD	Netherlands	EU27	WI	WI	13.898	66.673	258.596
NOR	Norway	CIS & other European countries	CEM	CEM	52.868	145.241	1066.527
NOR	Norway	CIS & other European countries	CREM	CREM	0.145	0.485	1.600
NOR	Norway	CIS & other European countries	NFMP-AL	AL-P	3.500	10.000	19.500
NOR	Norway	CIS & other European countries	NFMP-ZN	ZN-P	190.165	284.672	441.780
NOR	Norway	CIS & other European countries	OR	CO-OR	32.187	67.762	111.807
NOR	Norway	CIS & other European countries	PISP	PIP	1.077	2.565	18.340
NOR	Norway	CIS & other European countries	SC-DR-gas	NG-DR	0.010	0.021	0.034
NOR	Norway	CIS & other European countries	SC-DR-oil	CO-HF-DR	1.045	2.200	3.630
NOR	Norway	CIS & other European countries	SC-DR-oil	CO-LF-DR	3.382	7.120	11.748
NOR	Norway	CIS & other European countries	SC-IND-coal	HC-IND	22.744	34.202	48.909
NOR	Norway	CIS & other European countries	SC-IND-gas	NG-IND	0.023	0.049	0.081
NOR	Norway	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.857	1.805	2.978
NOR	Norway	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.324	0.682	1.125
NOR	Norway	CIS & other European countries	SC-PP-coal	HC-B-PP	0.895	1.346	1.924
NOR	Norway	CIS & other European countries	SC-PP-gas	NG-PP	0.484	1.019	1.681
NOR	Norway	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.199	0.419	0.692
NOR	Norway	CIS & other European countries	WASOTH	WASOTH	20.939	80.963	276.392
NOR	Norway	CIS & other European countries	WI	WI	7.599	29.384	100.311
NPL	Nepal	South Asia	CEM	CEM	9.450	26.100	94.965
NPL	Nepal	South Asia	CREM	CREM	3.994	16.816	58.855
NPL	Nepal	South Asia	SC-DR-coal	HC-DR	0.095	0.150	0.215
NPL	Nepal	South Asia	SC-DR-oil	CO-LF-DR	0.446	0.992	1.637
NPL	Nepal	South Asia	SC-IND-coal	HC-IND	28.439	45.141	64.551
NPL	Nepal	South Asia	SC-IND-oil	CO-LF-IND	0.006	0.014	0.023
NPL	Nepal	South Asia	SC-PP-oil	CO-HF-PP	0.036	0.080	0.132
NPL	Nepal	South Asia	WASOTH	WASOTH	27.594	116.360	412.246
NPL	Nepal	South Asia	WI	WI	0.086	0.362	1.281
NRU	Nauru	Australia, New Zealand & Oceania	CREM	CREM	0.012	0.054	0.201
NRU	Nauru	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.034	0.122	0.421
NRU	Nauru	Australia, New Zealand & Oceania	WI	WI	0.000	0.000	0.001
NZL	New Zealand	Australia, New Zealand & Oceania	CEM	CEM	23.909	66.033	240.261
NZL	New Zealand	Australia, New Zealand & Oceania	CREM	CREM	3.567	15.853	59.450
NZL	New Zealand	Australia, New Zealand & Oceania	NFMP-AL	AL-P	3.010	8.600	16.770
NZL	New Zealand	Australia, New Zealand & Oceania	NFMP-AU	GP-L	2.536	362.262	941.881
NZL	New Zealand	Australia, New Zealand & Oceania	OR	CO-OR	7.734	16.283	26.866
NZL	New Zealand	Australia, New Zealand & Oceania	PISP	PIP	11.626	27.681	197.916
NZL	New Zealand	Australia, New Zealand & Oceania	SC-DR-coal	BC-DR	14.005	21.060	30.116
NZL	New Zealand	Australia, New Zealand & Oceania	SC-DR-coal	HC-DR	2.531	3.806	5.443
NZL	New Zealand	Australia, New Zealand & Oceania	SC-DR-gas	NG-DR	0.035	0.074	0.121
NZL	New Zealand	Australia, New Zealand & Oceania	SC-DR-oil	CO-HF-DR	0.295	0.620	1.023

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
NZL	New Zealand	Australia, New Zealand & Oceania	SC-DR-oil	CO-LF-DR	2.018	4.248	7.009
NZL	New Zealand	Australia, New Zealand & Oceania	SC-IND-coal	BC-IND	45.070	67.774	96.916
NZL	New Zealand	Australia, New Zealand & Oceania	SC-IND-coal	HC-IND	5.835	8.775	12.548
NZL	New Zealand	Australia, New Zealand & Oceania	SC-IND-gas	NG-IND	0.095	0.200	0.330
NZL	New Zealand	Australia, New Zealand & Oceania	SC-IND-oil	CO-HF-IND	0.099	0.209	0.345
NZL	New Zealand	Australia, New Zealand & Oceania	SC-IND-oil	CO-LF-IND	0.275	0.580	0.956
NZL	New Zealand	Australia, New Zealand & Oceania	SC-PP-coal	BC-L-PP	1.219	1.834	2.622
NZL	New Zealand	Australia, New Zealand & Oceania	SC-PP-coal	BC-S-PP	103.578	155.756	222.731
NZL	New Zealand	Australia, New Zealand & Oceania	SC-PP-gas	NG-PP	0.196	0.412	0.679
NZL	New Zealand	Australia, New Zealand & Oceania	SC-PP-oil	CO-LF-PP	0.002	0.004	0.006
NZL	New Zealand	Australia, New Zealand & Oceania	WASOTH	WASOTH	14.351	51.823	179.388
OMN	Oman	Middle Eastern States	CEM	CEM	85.428	235.944	858.484
OMN	Oman	Middle Eastern States	CREM	CREM	0.144	0.638	2.273
OMN	Oman	Middle Eastern States	NFMP-AL	AL-P	1.606	4.588	8.946
OMN	Oman	Middle Eastern States	NFMP-AU	GP-L	0.001	0.077	0.200
OMN	Oman	Middle Eastern States	NFMP-CU	CU-P	8.240	23.112	115.690
OMN	Oman	Middle Eastern States	OR	CO-OR	1.848	4.106	6.775
OMN	Oman	Middle Eastern States	SC-DR-gas	NG-DR	0.016	0.036	0.060
OMN	Oman	Middle Eastern States	SC-DR-oil	CO-LF-DR	0.415	0.922	1.521
OMN	Oman	Middle Eastern States	SC-IND-gas	NG-IND	0.036	0.079	0.130
OMN	Oman	Middle Eastern States	SC-IND-oil	CO-HF-IND	14.603	32.452	53.546
OMN	Oman	Middle Eastern States	SC-PP-gas	NG-PP	0.794	1.765	2.913
OMN	Oman	Middle Eastern States	SC-PP-oil	CO-HF-PP	3.345	7.434	12.266
OMN	Oman	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.863	1.919	3.166
OMN	Oman	Middle Eastern States	WASOTH	WASOTH	17.626	70.125	233.117
OMN	Oman	Middle Eastern States	WI	WI	0.508	2.020	6.716
PAK	Pakistan	South Asia	CEM	CEM	1008.000	2784.000	10129.600
PAK	Pakistan	South Asia	CREM	CREM	0.722	3.041	10.643
PAK	Pakistan	South Asia	CSP	CSP-C	231.000	660.000	1287.000
PAK	Pakistan	South Asia	NFMP-CU	CU-P	96.806	271.513	1359.085
PAK	Pakistan	South Asia	OR	CO-OR	15.098	33.551	55.359
PAK	Pakistan	South Asia	PISP	PIP	15.750	37.500	268.125
PAK	Pakistan	South Asia	SC-DR-gas	NG-DR	0.827	1.838	3.032
PAK	Pakistan	South Asia	SC-DR-oil	CO-HF-DR	1.521	3.380	5.577
PAK	Pakistan	South Asia	SC-DR-oil	CO-LF-DR	5.971	13.268	21.892
PAK	Pakistan	South Asia	SC-IND-coal	BC-IND	111.983	177.750	254.183
PAK	Pakistan	South Asia	SC-IND-coal	HC-IND	565.405	897.469	1283.380
PAK	Pakistan	South Asia	SC-IND-gas	NG-IND	0.837	1.861	3.070
PAK	Pakistan	South Asia	SC-IND-oil	CO-HF-IND	4.194	9.320	15.378
PAK	Pakistan	South Asia	SC-IND-oil	CO-LF-IND	0.407	0.904	1.492
PAK	Pakistan	South Asia	SC-PP-coal	HC-B-PP	8.859	14.063	20.109
PAK	Pakistan	South Asia	SC-PP-gas	NG-PP	0.736	1.635	2.698
PAK	Pakistan	South Asia	SC-PP-oil	CO-HF-PP	78.525	174.500	287.925
PAK	Pakistan	South Asia	SC-PP-oil	CO-LF-PP	0.225	0.500	0.825
PAK	Pakistan	South Asia	WASOTH	WASOTH	361.124	1522.812	5395.107
PAK	Pakistan	South Asia	WI	WI	1.122	4.732	16.765
PAN	Panama	Central America and the Caribbean	ASGM	ASGM	187.500	750.000	1312.500
PAN	Panama	Central America and the Caribbean	CEM	CEM	26.460	73.080	265.902
PAN	Panama	Central America and the Caribbean	CREM	CREM	0.534	2.162	7.250
PAN	Panama	Central America and the Caribbean	NFMP-AU	GP-L	0.222	31.680	82.368
PAN	Panama	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.009	0.020	0.033
PAN	Panama	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.420	0.934	1.541
PAN	Panama	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	0.487	1.083	1.787

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
PAN	Panama	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.289	0.642	1.060
PAN	Panama	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	4.762	10.583	17.462
PAN	Panama	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.103	0.230	0.379
PAN	Panama	Central America and the Caribbean	WASOTH	WASOTH	26.447	101.720	335.675
PAN	Panama	Central America and the Caribbean	WI	WI	0.082	0.316	1.043
PCN	Pitcairn	Australia, New Zealand & Oceania	CREM	CREM	0.000	0.000	0.001
PER	Peru	South America	ASGM	ASGM	18375.000	26250.000	34125.000
PER	Peru	South America	CEM	CEM	172.922	477.595	1737.733
PER	Peru	South America	CREM	CREM	15.746	59.725	206.322
PER	Peru	South America	CSP	CSP-C	133.000	380.000	741.000
PER	Peru	South America	NFMP-AU	GP-L	50.559	7222.684	18778.977
PER	Peru	South America	NFMP-CU	CU-P	1120.370	3142.323	15729.233
PER	Peru	South America	NFMP-PB	PB-P	12.240	34.640	72.160
PER	Peru	South America	NFMP-ZN	ZN-P	346.901	881.865	3768.004
PER	Peru	South America	OR	CO-OR	4.221	9.380	15.477
PER	Peru	South America	PISP	PIP	7.571	18.025	128.879
PER	Peru	South America	SC-DR-gas	NG-DR	0.034	0.076	0.126
PER	Peru	South America	SC-DR-oil	CO-HF-DR	1.683	3.740	6.171
PER	Peru	South America	SC-DR-oil	CO-LF-DR	2.994	6.654	10.979
PER	Peru	South America	SC-IND-coal	HC-IND	55.495	88.088	125.965
PER	Peru	South America	SC-IND-gas	NG-IND	0.060	0.133	0.220
PER	Peru	South America	SC-IND-oil	CO-HF-IND	6.165	13.699	22.603
PER	Peru	South America	SC-IND-oil	CO-LF-IND	0.557	1.237	2.041
PER	Peru	South America	SC-PP-coal	HC-B-PP	23.538	37.361	53.427
PER	Peru	South America	SC-PP-gas	NG-PP	0.335	0.744	1.228
PER	Peru	South America	SC-PP-oil	CO-HF-PP	3.685	8.189	13.512
PER	Peru	South America	SC-PP-oil	CO-LF-PP	0.237	0.526	0.868
PER	Peru	South America	WASOTH	WASOTH	172.580	664.533	2261.395
PER	Peru	South America	WI	WI	0.536	2.065	7.027
PHL	Philippines	East and Southeast Asia	ASGM	ASGM	18375.000	26250.000	34125.000
PHL	Philippines	East and Southeast Asia	CEM	CEM	374.598	1034.604	3764.413
PHL	Philippines	East and Southeast Asia	CREM	CREM	26.176	94.289	299.755
PHL	Philippines	East and Southeast Asia	CSP	CSP-C	24.500	70.000	136.500
PHL	Philippines	East and Southeast Asia	NFMP-AU	GP-L	10.269	1467.061	3814.359
PHL	Philippines	East and Southeast Asia	NFMP-CU	CU-P	746.157	2092.760	10475.533
PHL	Philippines	East and Southeast Asia	OR	CO-OR	10.721	23.824	39.309
PHL	Philippines	East and Southeast Asia	SC-DR-oil	CO-HF-DR	3.780	8.400	13.860
PHL	Philippines	East and Southeast Asia	SC-DR-oil	CO-LF-DR	4.446	9.880	16.302
PHL	Philippines	East and Southeast Asia	SC-IND-coal	BC-IND	223.544	354.833	507.410
PHL	Philippines	East and Southeast Asia	SC-IND-gas	NG-IND	0.007	0.016	0.027
PHL	Philippines	East and Southeast Asia	SC-IND-oil	CO-HF-IND	6.780	15.067	24.861
PHL	Philippines	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.398	0.884	1.458
PHL	Philippines	East and Southeast Asia	SC-PP-coal	HC-B-PP	536.836	852.120	1218.532
PHL	Philippines	East and Southeast Asia	SC-PP-gas	NG-PP	0.329	0.731	1.206
PHL	Philippines	East and Southeast Asia	SC-PP-oil	CO-HF-PP	7.986	17.746	29.281
PHL	Philippines	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.221	0.492	0.812
PHL	Philippines	East and Southeast Asia	WASOTH	WASOTH	206.890	818.939	2822.246
PHL	Philippines	East and Southeast Asia	WI	WI	5.960	23.593	81.308
PLW	Palau	Australia, New Zealand & Oceania	CREM	CREM	0.019	0.082	0.309
PLW	Palau	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.158	0.570	1.973
PLW	Palau	Australia, New Zealand & Oceania	WI	WI	0.000	0.002	0.006
PNG	Papua New Guinea	East and Southeast Asia	ASGM	ASGM	875.000	3500.000	6125.000
PNG	Papua New Guinea	East and Southeast Asia	CREM	CREM	1.975	7.113	22.614

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
PNG	Papua New Guinea	East and Southeast Asia	NFMP-AU	GP-L	18.295	2613.600	6795.360
PNG	Papua New Guinea	East and Southeast Asia	WASOTH	WASOTH	14.510	57.434	197.929
PNG	Papua New Guinea	East and Southeast Asia	WI	WI	0.045	0.178	0.615
POL	Poland	EU27	CEM	CEM	268.058	718.990	2763.423
POL	Poland	EU27	CREM	CREM	1.323	4.899	16.166
POL	Poland	EU27	CSP	CSP-C	109.617	313.190	610.721
POL	Poland	EU27	NFMP-AU	GP-L	0.016	2.239	5.820
POL	Poland	EU27	NFMP-CU	CU-P	280.311	786.193	3935.375
POL	Poland	EU27	NFMP-PB	PB-P	2.363	6.750	13.163
POL	Poland	EU27	NFMP-ZN	ZN-T	115.676	307.967	756.774
POL	Poland	EU27	OR	CO-OR	32.791	69.034	113.905
POL	Poland	EU27	PISP	PIP	39.192	93.315	667.200
POL	Poland	EU27	SC-DR-coal	BC-DR	51.546	77.513	110.843
POL	Poland	EU27	SC-DR-coal	HC-DR	1030.530	1549.669	2216.026
POL	Poland	EU27	SC-DR-gas	NG-DR	0.576	1.213	2.002
POL	Poland	EU27	SC-DR-oil	CO-HF-DR	0.285	0.600	0.990
POL	Poland	EU27	SC-DR-oil	CO-LF-DR	10.419	21.934	36.191
POL	Poland	EU27	SC-IND-coal	BC-IND	1.324	1.991	2.847
POL	Poland	EU27	SC-IND-coal	HC-IND	246.404	370.532	529.861
POL	Poland	EU27	SC-IND-gas	NG-IND	0.324	0.682	1.125
POL	Poland	EU27	SC-IND-oil	CO-HF-IND	1.706	3.591	5.925
POL	Poland	EU27	SC-IND-oil	CO-LF-IND	0.404	0.851	1.404
POL	Poland	EU27	SC-PP-coal	BC-L-PP	3114.634	4683.661	6697.635
POL	Poland	EU27	SC-PP-coal	HC-B-PP	1629.181	2449.897	3503.352
POL	Poland	EU27	SC-PP-gas	NG-PP	0.206	0.433	0.715
POL	Poland	EU27	SC-PP-oil	CO-HF-PP	10.867	22.878	37.749
POL	Poland	EU27	SC-PP-oil	CO-LF-PP	0.053	0.112	0.184
POL	Poland	EU27	WASOTH	WASOTH	41.214	197.714	766.853
POL	Poland	EU27	WI	WI	14.958	71.757	278.315
PRI	Puerto Rico	Central America and the Caribbean	CREM	CREM	0.696	2.818	9.450
PRI	Puerto Rico	Central America and the Caribbean	WASOTH	WASOTH	35.137	135.143	445.972
PRI	Puerto Rico	Central America and the Caribbean	WI	WI	0.109	0.420	1.386
PRK	Korea- Dem. Rep.	East and Southeast Asia	CEM	CEM	176.400	487.200	1772.680
PRK	Korea- Dem. Rep.	East and Southeast Asia	CREM	CREM	7.430	26.763	85.082
PRK	Korea- Dem. Rep.	East and Southeast Asia	CSP	CSP-C	175.000	500.000	975.000
PRK	Korea- Dem. Rep.	East and Southeast Asia	NFMP-AU	GP-L	0.693	99.000	257.400
PRK	Korea- Dem. Rep.	East and Southeast Asia	NFMP-CU	CU-T	68.670	192.600	964.080
PRK	Korea- Dem. Rep.	East and Southeast Asia	NFMP-PB	PB-T	7.201	20.250	43.980
PRK	Korea- Dem. Rep.	East and Southeast Asia	NFMP-ZN	ZN-T	415.800	1107.000	2720.250
PRK	Korea- Dem. Rep.	East and Southeast Asia	OR	CO-OR	0.525	1.166	1.924
PRK	Korea- Dem. Rep.	East and Southeast Asia	PISP	PIP	5.040	12.000	85.800
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-DR-coal	BC-DR	221.036	350.850	501.716
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-DR-coal	HC-DR	349.745	555.150	793.865
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-DR-oil	CO-LF-DR	0.151	0.336	0.554
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-IND-coal	BC-IND	365.233	579.735	829.021
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-IND-coal	HC-IND	1183.754	1878.975	2686.934
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-IND-oil	CO-HF-IND	0.540	1.200	1.980
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-PP-coal	BC-S-PP	55.368	87.885	125.676
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-PP-coal	HC-B-PP	255.504	405.563	579.954
PRK	Korea- Dem. Rep.	East and Southeast Asia	SC-PP-oil	CO-HF-PP	2.493	5.540	9.141
PRK	Korea- Dem. Rep.	East and Southeast Asia	WASOTH	WASOTH	34.491	136.527	470.503
PRK	Korea- Dem. Rep.	East and Southeast Asia	WI	WI	0.107	0.424	1.462
PRT	Portugal	EU27	CEM	CEM	201.225	555.765	2022.153

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
PRT	Portugal	EU27	CREM	CREM	2.744	10.161	33.532
PRT	Portugal	EU27	OR	CO-OR	16.806	35.380	58.378
PRT	Portugal	EU27	PISP	PIP	1.077	2.565	18.340
PRT	Portugal	EU27	SC-DR-gas	NG-DR	0.053	0.112	0.185
PRT	Portugal	EU27	SC-DR-oil	CO-HF-DR	1.568	3.300	5.445
PRT	Portugal	EU27	SC-DR-oil	CO-LF-DR	4.674	9.840	16.236
PRT	Portugal	EU27	SC-IND-coal	HC-IND	1.384	2.081	2.976
PRT	Portugal	EU27	SC-IND-gas	NG-IND	0.106	0.222	0.366
PRT	Portugal	EU27	SC-IND-oil	CO-HF-IND	2.834	5.966	9.844
PRT	Portugal	EU27	SC-IND-oil	CO-LF-IND	0.238	0.502	0.828
PRT	Portugal	EU27	SC-PP-coal	HC-B-PP	159.611	240.017	343.224
PRT	Portugal	EU27	SC-PP-gas	NG-PP	0.295	0.620	1.023
PRT	Portugal	EU27	SC-PP-oil	CO-HF-PP	8.259	17.388	28.690
PRT	Portugal	EU27	SC-PP-oil	CO-LF-PP	0.019	0.040	0.065
PRT	Portugal	EU27	WASOTH	WASOTH	14.869	71.333	276.670
PRT	Portugal	EU27	WI	WI	5.397	25.889	100.412
PRY	Paraguay	South America	ASGM	ASGM	56.250	225.000	393.750
PRY	Paraguay	South America	CEM	CEM	15.120	41.760	151.944
PRY	Paraguay	South America	CREM	CREM	1.671	6.339	21.899
PRY	Paraguay	South America	PISP	PIP	1.488	3.544	25.338
PRY	Paraguay	South America	SC-DR-oil	CO-LF-DR	0.856	1.902	3.138
PRY	Paraguay	South America	SC-IND-oil	CO-HF-IND	0.239	0.532	0.878
PRY	Paraguay	South America	WASOTH	WASOTH	20.696	79.691	271.187
PRY	Paraguay	South America	WI	WI	0.064	0.248	0.843
PSE	Occupied Palestinian Territories	Middle Eastern States	CREM	CREM	0.341	1.516	5.401
PSE	Occupied Palestinian Territories	Middle Eastern States	WASOTH	WASOTH	3.327	13.238	44.007
PSE	Occupied Palestinian Territories	Middle Eastern States	WI	WI	0.010	0.041	0.137
PYF	French Polynesia	Australia, New Zealand & Oceania	CREM	CREM	0.248	1.104	4.139
PYF	French Polynesia	Australia, New Zealand & Oceania	WASOTH	WASOTH	2.650	9.568	33.119
PYF	French Polynesia	Australia, New Zealand & Oceania	WI	WI	0.008	0.030	0.103
QAT	Qatar	Middle Eastern States	CEM	CEM	88.632	244.792	890.677
QAT	Qatar	Middle Eastern States	CREM	CREM	0.150	0.666	2.371
QAT	Qatar	Middle Eastern States	NFMP-AL	AL-P	0.831	2.375	4.631
QAT	Qatar	Middle Eastern States	OR	CO-OR	1.142	2.538	4.187
QAT	Qatar	Middle Eastern States	SC-DR-oil	CO-LF-DR	0.970	2.156	3.557
QAT	Qatar	Middle Eastern States	SC-IND-gas	NG-IND	0.376	0.835	1.378
QAT	Qatar	Middle Eastern States	SC-PP-gas	NG-PP	1.386	3.079	5.080
QAT	Qatar	Middle Eastern States	WASOTH	WASOTH	31.373	124.817	414.932
QAT	Qatar	Middle Eastern States	WI	WI	0.904	3.596	11.954
REU	Reunion	Sub-Saharan Africa	CEM	CEM	11.813	32.625	118.706
REU	Reunion	Sub-Saharan Africa	CREM	CREM	0.029	0.118	0.412
ROU	Romania	EU27	CEM	CEM	214.988	593.775	2160.454
ROU	Romania	EU27	CREM	CREM	0.686	2.287	7.548
ROU	Romania	EU27	CSP	CSP-C	162.750	465.000	906.750
ROU	Romania	EU27	NFMP-AL	AL-P	3.623	10.350	20.183
ROU	Romania	EU27	NFMP-AU	GP-L	0.139	19.800	51.480
ROU	Romania	EU27	NFMP-PB	PB-P	7.201	20.250	43.980
ROU	Romania	EU27	NFMP-ZN	ZN-T	22.176	59.040	145.080
ROU	Romania	EU27	OR	CO-OR	17.151	38.114	62.888
ROU	Romania	EU27	PISP	PIP	34.796	82.848	592.363
ROU	Romania	EU27	SC-DR-coal	BC-DR	6.993	11.100	15.873

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
ROU	Romania	EU27	SC-DR-gas	NG-DR	0.334	0.742	1.225
ROU	Romania	EU27	SC-DR-oil	CO-HF-DR	0.189	0.420	0.693
ROU	Romania	EU27	SC-DR-oil	CO-LF-DR	3.106	6.902	11.388
ROU	Romania	EU27	SC-IND-coal	BC-IND	99.509	157.950	225.869
ROU	Romania	EU27	SC-IND-coal	HC-IND	4.713	7.481	10.698
ROU	Romania	EU27	SC-IND-gas	NG-IND	0.281	0.624	1.029
ROU	Romania	EU27	SC-IND-oil	CO-HF-IND	0.567	1.260	2.079
ROU	Romania	EU27	SC-IND-oil	CO-LF-IND	0.212	0.472	0.779
ROU	Romania	EU27	SC-PP-coal	BC-L-PP	1988.522	3156.384	4513.629
ROU	Romania	EU27	SC-PP-coal	BC-S-PP	31.979	50.760	72.587
ROU	Romania	EU27	SC-PP-gas	NG-PP	0.379	0.842	1.389
ROU	Romania	EU27	SC-PP-oil	CO-HF-PP	4.302	9.560	15.774
ROU	Romania	EU27	SC-PP-oil	CO-LF-PP	0.079	0.176	0.290
ROU	Romania	EU27	SC-PP-oil	CO-PP	0.014	0.030	0.050
ROU	Romania	EU27	WASOTH	WASOTH	67.045	321.631	359.732
ROU	Romania	EU27	WI	WI	1.932	9.266	10.364
RUS	Russia	CIS & other European countries	ASGM	ASGM	1375.000	5500.000	9625.000
RUS	Russia	CIS & other European countries	CEM	CEM	868.280	1279.163	2721.128
RUS	Russia	CIS & other European countries	CREM	CREM	22.744	75.815	250.189
RUS	Russia	CIS & other European countries	CSP	CSP-C	2807.000	8020.000	15639.000
RUS	Russia	CIS & other European countries	NFMP-AL	AL-P	497.322	1263.040	2616.861
RUS	Russia	CIS & other European countries	NFMP-AU	GP-L	66.075	9439.304	24542.189
RUS	Russia	CIS & other European countries	NFMP-CU	CU-P	2655.240	7447.200	37277.760
RUS	Russia	CIS & other European countries	NFMP-HG	HG-P	196.875	337.500	511.875
RUS	Russia	CIS & other European countries	NFMP-PB	PB-T	58.407	164.250	356.729
RUS	Russia	CIS & other European countries	NFMP-ZN	ZN-T	1443.960	3893.400	8211.645
RUS	Russia	CIS & other European countries	OR	CO-OR	343.603	763.562	1259.877
RUS	Russia	CIS & other European countries	PISP	PIP	2512.509	6074.196	11725.040
RUS	Russia	CIS & other European countries	SC-DR-coal	BC-DR	91.665	145.500	208.065
RUS	Russia	CIS & other European countries	SC-DR-coal	HC-DR	438.480	696.000	995.280
RUS	Russia	CIS & other European countries	SC-DR-gas	NG-DR	7.624	16.942	27.954
RUS	Russia	CIS & other European countries	SC-DR-oil	CO-DR	0.126	0.280	0.462
RUS	Russia	CIS & other European countries	SC-DR-oil	CO-HF-DR	12.717	28.260	46.629
RUS	Russia	CIS & other European countries	SC-DR-oil	CO-LF-DR	19.509	43.354	71.534
RUS	Russia	CIS & other European countries	SC-IND-coal	BC-IND	26.474	42.023	60.092
RUS	Russia	CIS & other European countries	SC-IND-coal	HC-IND	84.066	133.438	190.816
RUS	Russia	CIS & other European countries	SC-IND-gas	NG-IND	3.078	6.840	11.286
RUS	Russia	CIS & other European countries	SC-IND-oil	CO-HF-IND	12.753	28.340	46.761
RUS	Russia	CIS & other European countries	SC-IND-oil	CO-IND	0.059	0.130	0.215
RUS	Russia	CIS & other European countries	SC-IND-oil	CO-LF-IND	2.056	4.568	7.537
RUS	Russia	CIS & other European countries	SC-PP-coal	BC-L-PP	2468.469	3918.205	5603.033
RUS	Russia	CIS & other European countries	SC-PP-coal	HC-B-PP	2691.786	4272.677	6109.928
RUS	Russia	CIS & other European countries	SC-PP-gas	NG-PP	22.613	50.250	82.913
RUS	Russia	CIS & other European countries	SC-PP-oil	CO-HF-PP	103.212	229.360	378.444
RUS	Russia	CIS & other European countries	SC-PP-oil	CO-LF-PP	3.518	7.818	12.900
RUS	Russia	CIS & other European countries	SC-PP-oil	CO-PP	4.550	10.110	16.682
RUS	Russia	CIS & other European countries	WASOTH	WASOTH	1316.007	5088.561	17371.294
RUS	Russia	CIS & other European countries	WI	WI	4.089	15.813	53.981
RWA	Rwanda	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
RWA	Rwanda	Sub-Saharan Africa	CEM	CEM	3.150	8.700	31.655
RWA	Rwanda	Sub-Saharan Africa	CREM	CREM	0.319	1.276	4.465
RWA	Rwanda	Sub-Saharan Africa	NFMP-AU	GP-L	0.008	1.100	2.860
RWA	Rwanda	Sub-Saharan Africa	WASOTH	WASOTH	7.033	28.542	94.799

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
RWA	Rwanda	Sub-Saharan Africa	WI	WI	0.022	0.089	0.295
SAU	Saudi Arabia	Middle Eastern States	CEM	CEM	854.280	2359.440	8584.836
SAU	Saudi Arabia	Middle Eastern States	CREM	CREM	0.382	1.696	6.043
SAU	Saudi Arabia	Middle Eastern States	NFMP-AU	GP-L	0.106	15.125	39.325
SAU	Saudi Arabia	Middle Eastern States	OR	CO-OR	15.716	34.924	57.625
SAU	Saudi Arabia	Middle Eastern States	SC-DR-oil	CO-LF-DR	13.112	29.138	48.078
SAU	Saudi Arabia	Middle Eastern States	SC-IND-oil	CO-HF-IND	63.484	141.075	232.774
SAU	Saudi Arabia	Middle Eastern States	SC-IND-oil	CO-IND	21.037	46.750	77.137
SAU	Saudi Arabia	Middle Eastern States	SC-IND-oil	CO-LF-IND	2.675	5.945	9.809
SAU	Saudi Arabia	Middle Eastern States	SC-PP-gas	NG-PP	5.014	11.142	18.384
SAU	Saudi Arabia	Middle Eastern States	SC-PP-oil	CO-HF-PP	41.132	91.404	150.817
SAU	Saudi Arabia	Middle Eastern States	SC-PP-oil	CO-LF-PP	9.640	21.422	35.346
SAU	Saudi Arabia	Middle Eastern States	SC-PP-oil	CO-PP	68.538	152.307	251.307
SAU	Saudi Arabia	Middle Eastern States	WASOTH	WASOTH	152.583	607.050	2018.030
SAU	Saudi Arabia	Middle Eastern States	WI	WI	4.396	17.489	58.139
SCG	Serbia and Montenegro	CIS & other European countries	CEM	CEM	61.519	169.911	618.222
SCG	Serbia and Montenegro	CIS & other European countries	CREM	CREM	0.484	1.612	5.321
SCG	Serbia and Montenegro	CIS & other European countries	CSP	CSP-C	70.000	200.000	390.000
SCG	Serbia and Montenegro	CIS & other European countries	NFMP-AL	AL-P	1.400	4.000	7.800
SCG	Serbia and Montenegro	CIS & other European countries	NFMP-AU	GP-L	0.173	24.750	64.350
SCG	Serbia and Montenegro	CIS & other European countries	NFMP-CU	CU-P	146.496	410.880	2056.704
SCG	Serbia and Montenegro	CIS & other European countries	NFMP-PB	PB-T	0.720	2.025	4.398
SCG	Serbia and Montenegro	CIS & other European countries	NFMP-ZN	ZN-P	30.420	80.988	199.013
SCG	Serbia and Montenegro	CIS & other European countries	OR	CO-OR	4.406	9.792	16.157
SCG	Serbia and Montenegro	CIS & other European countries	PISP	PIP	24.898	59.280	423.852
SCG	Serbia and Montenegro	CIS & other European countries	SC-DR-coal	BC-DR	115.479	183.300	262.119
SCG	Serbia and Montenegro	CIS & other European countries	SC-DR-gas	NG-DR	0.032	0.072	0.119
SCG	Serbia and Montenegro	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.594	1.320	2.178
SCG	Serbia and Montenegro	CIS & other European countries	SC-DR-oil	CO-LF-DR	1.155	2.566	4.234
SCG	Serbia and Montenegro	CIS & other European countries	SC-IND-coal	BC-IND	17.783	28.226	40.364
SCG	Serbia and Montenegro	CIS & other European countries	SC-IND-coal	HC-IND	1.158	1.838	2.628
SCG	Serbia and Montenegro	CIS & other European countries	SC-IND-gas	NG-IND	0.052	0.115	0.189
SCG	Serbia and Montenegro	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.693	1.540	2.541
SCG	Serbia and Montenegro	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.118	0.262	0.432
SCG	Serbia and Montenegro	CIS & other European countries	SC-PP-coal	BC-L-PP	2268.389	3600.618	5148.884
SCG	Serbia and Montenegro	CIS & other European countries	SC-PP-coal	BC-S-PP	2.977	4.725	6.757
SCG	Serbia and Montenegro	CIS & other European countries	SC-PP-gas	NG-PP	0.053	0.118	0.195
SCG	Serbia and Montenegro	CIS & other European countries	SC-PP-oil	CO-HF-PP	3.591	7.980	13.167
SCG	Serbia and Montenegro	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.049	0.108	0.178
SCG	Serbia and Montenegro	CIS & other European countries	WASOTH	WASOTH	25.409	98.248	335.399
SCG	Serbia and Montenegro	CIS & other European countries	WI	WI	0.732	2.830	9.663
SDN	Sudan	Sub-Saharan Africa	ASGM	ASGM	22500.000	45000.000	67500.000
SDN	Sudan	Sub-Saharan Africa	CEM	CEM	31.500	87.000	316.550
SDN	Sudan	Sub-Saharan Africa	CREM	CREM	0.901	3.605	12.617
SDN	Sudan	Sub-Saharan Africa	NFMP-AU	GP-L	0.740	105.710	274.846
SDN	Sudan	Sub-Saharan Africa	OR	CO-OR	1.532	3.406	5.619
SDN	Sudan	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	1.531	3.402	5.613
SDN	Sudan	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	2.637	5.860	9.669
SDN	Sudan	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.144	0.320	0.528
SDN	Sudan	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	3.510	7.800	12.870
SDN	Sudan	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.481	1.068	1.762
SDN	Sudan	Sub-Saharan Africa	WASOTH	WASOTH	55.905	226.862	753.507
SDN	Sudan	Sub-Saharan Africa	WI	WI	0.174	0.705	2.342

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
SEN	Senegal	Sub-Saharan Africa	ASGM	ASGM	281.250	1125.000	1968.750
SEN	Senegal	Sub-Saharan Africa	CEM	CEM	94.500	261.000	949.650
SEN	Senegal	Sub-Saharan Africa	CREM	CREM	0.044	0.177	0.619
SEN	Senegal	Sub-Saharan Africa	NFMP-AU	GP-L	2.156	308.000	800.800
SEN	Senegal	Sub-Saharan Africa	OR	CO-OR	0.234	0.521	0.859
SEN	Senegal	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.447	0.994	1.640
SEN	Senegal	Sub-Saharan Africa	SC-IND-coal	HC-IND	22.503	35.719	51.078
SEN	Senegal	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.558	1.240	2.046
SEN	Senegal	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.032	0.070	0.116
SEN	Senegal	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.002	0.003	0.006
SEN	Senegal	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	4.599	10.220	16.863
SEN	Senegal	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.067	0.148	0.244
SEN	Senegal	Sub-Saharan Africa	WASOTH	WASOTH	13.663	55.445	184.158
SEN	Senegal	Sub-Saharan Africa	WI	WI	0.042	0.172	0.572
SGP	Singapore	East and Southeast Asia	CEM	CEM	4.347	12.006	43.684
SGP	Singapore	East and Southeast Asia	CREM	CREM	1.224	4.410	14.021
SGP	Singapore	East and Southeast Asia	OR	CO-OR	67.519	150.042	247.569
SGP	Singapore	East and Southeast Asia	SC-DR-gas	NG-DR	0.024	0.054	0.089
SGP	Singapore	East and Southeast Asia	SC-DR-oil	CO-LF-DR	1.560	3.466	5.719
SGP	Singapore	East and Southeast Asia	SC-IND-gas	NG-IND	0.041	0.091	0.151
SGP	Singapore	East and Southeast Asia	SC-PP-gas	NG-PP	0.677	1.505	2.483
SGP	Singapore	East and Southeast Asia	SC-PP-oil	CO-HF-PP	31.217	69.372	114.464
SGP	Singapore	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.324	0.720	1.188
SGP	Singapore	East and Southeast Asia	WASOTH	WASOTH	164.384	650.687	2242.413
SGP	Singapore	East and Southeast Asia	WI	WI	4.736	18.746	64.603
SHN	Saint Helena	Sub-Saharan Africa	CREM	CREM	0.000	0.001	0.004
SHN	Saint Helena	Sub-Saharan Africa	WASOTH	WASOTH	0.010	0.042	0.139
SHN	Saint Helena	Sub-Saharan Africa	WI	WI	0.000	0.000	0.000
SLB	Solomon Islands	Australia, New Zealand & Oceania	CREM	CREM	0.441	1.958	7.343
SLB	Solomon Islands	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.813	2.934	10.158
SLB	Solomon Islands	Australia, New Zealand & Oceania	WI	WI	0.003	0.009	0.032
SLE	Sierra Leone	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
SLE	Sierra Leone	Sub-Saharan Africa	CEM	CEM	7.875	21.750	79.138
SLE	Sierra Leone	Sub-Saharan Africa	CREM	CREM	0.161	0.644	2.255
SLE	Sierra Leone	Sub-Saharan Africa	NFMP-AU	GP-L	0.077	11.000	28.600
SLE	Sierra Leone	Sub-Saharan Africa	WASOTH	WASOTH	2.761	11.202	37.207
SLE	Sierra Leone	Sub-Saharan Africa	WI	WI	0.009	0.035	0.116
SLV	El Salvador	Central America and the Caribbean	ASGM	ASGM	56.250	225.000	393.750
SLV	El Salvador	Central America and the Caribbean	CEM	CEM	32.760	90.480	329.212
SLV	El Salvador	Central America and the Caribbean	CREM	CREM	1.083	4.386	14.705
SLV	El Salvador	Central America and the Caribbean	OR	CO-OR	0.380	0.844	1.393
SLV	El Salvador	Central America and the Caribbean	SC-DR-oil	CO-HF-DR	0.045	0.100	0.165
SLV	El Salvador	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.341	0.758	1.251
SLV	El Salvador	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	2.411	5.358	8.841
SLV	El Salvador	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.192	0.428	0.705
SLV	El Salvador	Central America and the Caribbean	SC-PP-oil	CO-HF-PP	5.053	11.229	18.528
SLV	El Salvador	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.007	0.015	0.025
SLV	El Salvador	Central America and the Caribbean	WASOTH	WASOTH	22.459	86.382	285.060
SLV	El Salvador	Central America and the Caribbean	WI	WI	0.070	0.268	0.886
SOM	Somalia	Sub-Saharan Africa	CREM	CREM	0.001	0.003	0.009
SOM	Somalia	Sub-Saharan Africa	WASOTH	WASOTH	3.380	13.717	45.560
SOM	Somalia	Sub-Saharan Africa	WI	WI	0.011	0.043	0.142
SPM	St. Pierre-Miquelon	Central America and the Caribbean	CREM	CREM	0.001	0.005	0.017

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
STP	Sao Tome and Principe	Sub-Saharan Africa	CREM	CREM	0.006	0.022	0.077
STP	Sao Tome and Principe	Sub-Saharan Africa	WASOTH	WASOTH	0.178	0.724	2.403
STP	Sao Tome and Principe	Sub-Saharan Africa	WI	WI	0.001	0.002	0.007
SUR	Suriname	South America	ASGM	ASGM	2812.500	5625.000	8437.500
SUR	Suriname	South America	CEM	CEM	1.638	4.524	16.461
SUR	Suriname	South America	CREM	CREM	0.060	0.229	0.792
SUR	Suriname	South America	NFMP-AU	GP-L	3.380	482.843	1255.391
SUR	Suriname	South America	WASOTH	WASOTH	2.458	9.463	32.202
SUR	Suriname	South America	WI	WI	0.008	0.029	0.100
SVK	Slovakia	EU27	CEM	CEM	47.708	131.764	479.425
SVK	Slovakia	EU27	CREM	CREM	1.395	5.166	17.047
SVK	Slovakia	EU27	CSP	CSP-C	66.922	191.205	372.850
SVK	Slovakia	EU27	NFMP-AL	AL-P	0.713	2.038	3.973
SVK	Slovakia	EU27	NFMP-AU	GP-L	0.004	0.550	1.430
SVK	Slovakia	EU27	OR	CO-OR	9.206	19.380	31.977
SVK	Slovakia	EU27	PISP	PIP	39.311	93.597	669.217
SVK	Slovakia	EU27	SC-DR-coal	BC-DR	18.673	28.080	40.154
SVK	Slovakia	EU27	SC-DR-coal	HC-DR	52.980	79.669	113.926
SVK	Slovakia	EU27	SC-DR-gas	NG-DR	0.245	0.517	0.852
SVK	Slovakia	EU27	SC-DR-oil	CO-HF-DR	0.067	0.140	0.231
SVK	Slovakia	EU27	SC-DR-oil	CO-LF-DR	1.063	2.238	3.693
SVK	Slovakia	EU27	SC-IND-coal	BC-IND	15.302	23.010	32.904
SVK	Slovakia	EU27	SC-IND-coal	HC-IND	25.374	38.156	54.563
SVK	Slovakia	EU27	SC-IND-gas	NG-IND	0.083	0.176	0.290
SVK	Slovakia	EU27	SC-IND-oil	CO-HF-IND	0.451	0.950	1.568
SVK	Slovakia	EU27	SC-IND-oil	CO-LF-IND	0.014	0.030	0.050
SVK	Slovakia	EU27	SC-PP-coal	BC-L-PP	158.951	239.024	341.805
SVK	Slovakia	EU27	SC-PP-coal	HC-A-PP	8.456	12.715	18.183
SVK	Slovakia	EU27	SC-PP-coal	HC-B-PP	19.926	29.963	42.847
SVK	Slovakia	EU27	SC-PP-gas	NG-PP	0.113	0.237	0.392
SVK	Slovakia	EU27	SC-PP-oil	CO-HF-PP	2.257	4.752	7.841
SVK	Slovakia	EU27	SC-PP-oil	CO-LF-PP	0.002	0.004	0.006
SVK	Slovakia	EU27	WASOTH	WASOTH	7.083	33.981	131.799
SVK	Slovakia	EU27	WI	WI	2.571	12.333	47.834
SVN	Slovenia	EU27	CEM	CEM	15.845	43.761	159.225
SVN	Slovenia	EU27	CREM	CREM	0.783	2.900	9.571
SVN	Slovenia	EU27	NFMP-AL	AL-P	0.175	0.500	0.975
SVN	Slovenia	EU27	SC-DR-gas	NG-DR	0.014	0.029	0.048
SVN	Slovenia	EU27	SC-DR-oil	CO-LF-DR	1.479	3.114	5.138
SVN	Slovenia	EU27	SC-IND-coal	BC-IND	3.899	5.863	8.384
SVN	Slovenia	EU27	SC-IND-coal	HC-IND	2.007	3.019	4.317
SVN	Slovenia	EU27	SC-IND-gas	NG-IND	0.050	0.104	0.172
SVN	Slovenia	EU27	SC-IND-oil	CO-HF-IND	0.144	0.304	0.502
SVN	Slovenia	EU27	SC-IND-oil	CO-LF-IND	0.074	0.156	0.257
SVN	Slovenia	EU27	SC-PP-coal	BC-L-PP	246.801	371.130	530.716
SVN	Slovenia	EU27	SC-PP-coal	BC-S-PP	30.188	45.396	64.916
SVN	Slovenia	EU27	SC-PP-gas	NG-PP	0.019	0.039	0.064
SVN	Slovenia	EU27	SC-PP-oil	CO-HF-PP	0.034	0.072	0.119
SVN	Slovenia	EU27	SC-PP-oil	CO-LF-PP	0.008	0.016	0.027
SVN	Slovenia	EU27	WASOTH	WASOTH	3.086	14.804	57.420
SVN	Slovenia	EU27	WI	WI	1.120	5.373	20.840
SWE	Sweden	EU27	CEM	CEM	31.595	83.951	331.517
SWE	Sweden	EU27	CREM	CREM	3.658	13.547	44.707

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
SWE	Sweden	EU27	CSP	CSP-C	10.500	30.000	58.500
SWE	Sweden	EU27	NFMP-AL	AL-P	0.407	1.163	2.267
SWE	Sweden	EU27	NFMP-AU	GP-L	0.096	13.750	35.750
SWE	Sweden	EU27	NFMP-CU	CU-P	86.524	242.676	1214.741
SWE	Sweden	EU27	NFMP-PB	PB-P	2.048	5.850	11.408
SWE	Sweden	EU27	OR	CO-OR	31.715	66.769	110.169
SWE	Sweden	EU27	PISP	PIP	37.135	88.416	632.171
SWE	Sweden	EU27	SC-DR-gas	NG-DR	0.018	0.038	0.062
SWE	Sweden	EU27	SC-DR-oil	CO-HF-DR	2.014	4.240	6.996
SWE	Sweden	EU27	SC-DR-oil	CO-LF-DR	3.787	7.972	13.154
SWE	Sweden	EU27	SC-IND-coal	HC-IND	38.504	57.900	82.797
SWE	Sweden	EU27	SC-IND-gas	NG-IND	0.045	0.094	0.156
SWE	Sweden	EU27	SC-IND-oil	CO-HF-IND	5.135	10.811	17.838
SWE	Sweden	EU27	SC-IND-oil	CO-LF-IND	0.197	0.414	0.683
SWE	Sweden	EU27	SC-PP-coal	HC-B-PP	6.159	9.261	13.243
SWE	Sweden	EU27	SC-PP-gas	NG-PP	0.061	0.128	0.211
SWE	Sweden	EU27	SC-PP-oil	CO-HF-PP	2.206	4.644	7.663
SWE	Sweden	EU27	SC-PP-oil	CO-LF-PP	0.078	0.164	0.270
SWE	Sweden	EU27	WASOTH	WASOTH	19.970	95.801	371.574
SWE	Sweden	EU27	WI	WI	7.248	34.769	134.856
SWZ	Swaziland	Sub-Saharan Africa	CREM	CREM	0.038	0.151	0.527
SWZ	Swaziland	Sub-Saharan Africa	WASOTH	WASOTH	3.422	13.887	46.124
SWZ	Swaziland	Sub-Saharan Africa	WI	WI	0.011	0.043	0.143
SYC	Seychelles	Sub-Saharan Africa	CREM	CREM	0.003	0.012	0.042
SYC	Seychelles	Sub-Saharan Africa	WASOTH	WASOTH	1.144	4.644	15.424
SYC	Seychelles	Sub-Saharan Africa	WI	WI	0.004	0.014	0.048
SYR	Syrian Arab Rep.	Middle Eastern States	CEM	CEM	141.246	390.108	1419.410
SYR	Syrian Arab Rep.	Middle Eastern States	CREM	CREM	1.080	4.799	17.097
SYR	Syrian Arab Rep.	Middle Eastern States	CSP	CSP-C	24.500	70.000	136.500
SYR	Syrian Arab Rep.	Middle Eastern States	OR	CO-OR	2.103	4.672	7.709
SYR	Syrian Arab Rep.	Middle Eastern States	SC-DR-gas	NG-DR	0.012	0.028	0.046
SYR	Syrian Arab Rep.	Middle Eastern States	SC-DR-oil	CO-HF-DR	1.620	3.600	5.940
SYR	Syrian Arab Rep.	Middle Eastern States	SC-DR-oil	CO-LF-DR	3.012	6.694	11.045
SYR	Syrian Arab Rep.	Middle Eastern States	SC-IND-gas	NG-IND	0.035	0.078	0.129
SYR	Syrian Arab Rep.	Middle Eastern States	SC-IND-oil	CO-HF-IND	7.071	15.713	25.926
SYR	Syrian Arab Rep.	Middle Eastern States	SC-IND-oil	CO-LF-IND	1.542	3.426	5.652
SYR	Syrian Arab Rep.	Middle Eastern States	SC-PP-gas	NG-PP	0.491	1.090	1.799
SYR	Syrian Arab Rep.	Middle Eastern States	SC-PP-oil	CO-HF-PP	43.596	96.881	159.854
SYR	Syrian Arab Rep.	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.527	1.170	1.931
SYR	Syrian Arab Rep.	Middle Eastern States	WASOTH	WASOTH	40.518	161.199	535.877
SYR	Syrian Arab Rep.	Middle Eastern States	WI	WI	0.126	0.501	1.665
TCA	Turks and Caicos Islands	Central America and the Caribbean	CREM	CREM	0.004	0.015	0.051
TCA	Turks and Caicos Islands	Central America and the Caribbean	WASOTH	WASOTH	0.117	0.450	1.486
TCA	Turks and Caicos Islands	Central America and the Caribbean	WI	WI	0.000	0.001	0.005
TCD	Chad	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
TCD	Chad	Sub-Saharan Africa	CREM	CREM	0.375	1.500	5.251
TCD	Chad	Sub-Saharan Africa	NFMP-AU	GP-L	0.039	5.500	14.300
TCD	Chad	Sub-Saharan Africa	WASOTH	WASOTH	8.754	35.523	117.988
TCD	Chad	Sub-Saharan Africa	WI	WI	0.027	0.110	0.367
TGO	Togo	Sub-Saharan Africa	ASGM	ASGM	750.000	3000.000	5250.000
TGO	Togo	Sub-Saharan Africa	CEM	CEM	25.200	69.600	253.240
TGO	Togo	Sub-Saharan Africa	CREM	CREM	0.140	0.562	1.966
TGO	Togo	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.091	0.202	0.333

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
TGO	Togo	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.171	0.380	0.627
TGO	Togo	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.002	0.004	0.007
TGO	Togo	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.007	0.016	0.026
TGO	Togo	Sub-Saharan Africa	WASOTH	WASOTH	3.423	13.892	46.140
TGO	Togo	Sub-Saharan Africa	WI	WI	0.011	0.043	0.143
THA	Thailand	East and Southeast Asia	ASGM	ASGM	281.250	1125.000	1968.750
THA	Thailand	East and Southeast Asia	CEM	CEM	677.719	1871.795	6810.538
THA	Thailand	East and Southeast Asia	CREM	CREM	18.599	66.998	212.993
THA	Thailand	East and Southeast Asia	NFMP-AU	GP-L	0.566	80.850	210.210
THA	Thailand	East and Southeast Asia	NFMP-ZN	ZN-P	241.845	643.874	1582.203
THA	Thailand	East and Southeast Asia	OR	CO-OR	2953.090	6562.423	10827.998
THA	Thailand	East and Southeast Asia	SC-DR-gas	NG-DR	0.121	0.268	0.443
THA	Thailand	East and Southeast Asia	SC-DR-oil	CO-HF-DR	0.036	0.080	0.132
THA	Thailand	East and Southeast Asia	SC-DR-oil	CO-LF-DR	13.053	29.006	47.860
THA	Thailand	East and Southeast Asia	SC-IND-coal	BC-IND	124.899	198.253	283.502
THA	Thailand	East and Southeast Asia	SC-IND-coal	HC-IND	590.353	937.069	1340.008
THA	Thailand	East and Southeast Asia	SC-IND-gas	NG-IND	0.221	0.492	0.811
THA	Thailand	East and Southeast Asia	SC-IND-oil	CO-HF-IND	8.379	18.620	30.723
THA	Thailand	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.873	1.940	3.201
THA	Thailand	East and Southeast Asia	SC-PP-coal	BC-L-PP	963.479	1529.332	2186.945
THA	Thailand	East and Southeast Asia	SC-PP-coal	HC-A-PP	29.835	47.357	67.721
THA	Thailand	East and Southeast Asia	SC-PP-coal	HC-B-PP	246.259	390.888	558.970
THA	Thailand	East and Southeast Asia	SC-PP-gas	NG-PP	2.447	5.437	8.971
THA	Thailand	East and Southeast Asia	SC-PP-oil	CO-HF-PP	1.199	2.664	4.396
THA	Thailand	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.018	0.040	0.065
THA	Thailand	East and Southeast Asia	WASOTH	WASOTH	330.450	1308.033	4507.775
THA	Thailand	East and Southeast Asia	WI	WI	9.520	37.684	129.867
TJK	Tajikistan	CIS & other European countries	ASGM	ASGM	750.000	3000.000	5250.000
TJK	Tajikistan	CIS & other European countries	CEM	CEM	5.237	14.464	52.626
TJK	Tajikistan	CIS & other European countries	CREM	CREM	0.116	0.388	1.279
TJK	Tajikistan	CIS & other European countries	NFMP-AL	AL-P	6.108	17.450	34.028
TJK	Tajikistan	CIS & other European countries	NFMP-AU	GP-L	0.472	67.370	175.161
TJK	Tajikistan	CIS & other European countries	NFMP-HG	HG-P	118.125	202.500	307.125
TJK	Tajikistan	CIS & other European countries	OR	CO-OR	0.034	0.075	0.123
TJK	Tajikistan	CIS & other European countries	SC-DR-coal	BC-DR	2.174	3.450	4.934
TJK	Tajikistan	CIS & other European countries	SC-DR-coal	HC-DR	17.577	27.900	39.897
TJK	Tajikistan	CIS & other European countries	SC-DR-gas	NG-DR	0.016	0.035	0.057
TJK	Tajikistan	CIS & other European countries	SC-DR-oil	CO-HF-DR	1.026	2.280	3.762
TJK	Tajikistan	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.194	0.430	0.710
TJK	Tajikistan	CIS & other European countries	SC-PP-gas	NG-PP	0.022	0.050	0.082
TJK	Tajikistan	CIS & other European countries	WASOTH	WASOTH	6.910	26.719	91.212
TJK	Tajikistan	CIS & other European countries	WI	WI	0.021	0.083	0.283
TKL	Tokelau	Australia, New Zealand & Oceania	CREM	CREM	0.001	0.006	0.022
TKL	Tokelau	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.001	0.003	0.011
TKL	Tokelau	Australia, New Zealand & Oceania	WI	WI	0.000	0.000	0.000
TKM	Turkmenistan	CIS & other European countries	CEM	CEM	24.806	68.513	249.283
TKM	Turkmenistan	CIS & other European countries	CREM	CREM	0.189	0.629	2.077
TKM	Turkmenistan	CIS & other European countries	OR	CO-OR	10.863	24.140	39.831
TKM	Turkmenistan	CIS & other European countries	SC-DR-gas	NG-DR	0.690	1.534	2.531
TKM	Turkmenistan	CIS & other European countries	SC-DR-oil	CO-HF-DR	9.657	21.460	35.409
TKM	Turkmenistan	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.933	2.074	3.422
TKM	Turkmenistan	CIS & other European countries	SC-IND-gas	NG-IND	0.066	0.147	0.242
TKM	Turkmenistan	CIS & other European countries	SC-PP-gas	NG-PP	0.822	1.826	3.012

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
TKM	Turkmenistan	CIS & other European countries	WASOTH	WASOTH	18.478	71.447	243.906
TKM	Turkmenistan	CIS & other European countries	WI	WI	0.057	0.222	0.758
TLS	Timor-Leste	East and Southeast Asia	CREM	CREM	0.336	1.209	3.843
TLS	Timor-Leste	East and Southeast Asia	WASOTH	WASOTH	0.892	3.533	12.174
TLS	Timor-Leste	East and Southeast Asia	WI	WI	0.003	0.011	0.038
TON	Tonga	Australia, New Zealand & Oceania	CREM	CREM	0.104	0.463	1.735
TON	Tonga	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.268	0.967	3.348
TON	Tonga	Australia, New Zealand & Oceania	WI	WI	0.001	0.003	0.010
TTO	Trinidad and Tobago	Central America and the Caribbean	CEM	CEM	23.940	66.120	240.578
TTO	Trinidad and Tobago	Central America and the Caribbean	CREM	CREM	0.104	0.422	1.416
TTO	Trinidad and Tobago	Central America and the Caribbean	OR	CO-OR	2.459	5.464	9.015
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-DR-gas	NG-DR	0.020	0.044	0.073
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-DR-oil	CO-LF-DR	0.382	0.848	1.399
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-IND-gas	NG-IND	0.369	0.820	1.353
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-IND-oil	CO-HF-IND	0.188	0.418	0.690
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-IND-oil	CO-LF-IND	0.048	0.106	0.176
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-PP-gas	NG-PP	0.529	1.175	1.939
TTO	Trinidad and Tobago	Central America and the Caribbean	SC-PP-oil	CO-LF-PP	0.026	0.057	0.094
TTO	Trinidad and Tobago	Central America and the Caribbean	WASOTH	WASOTH	18.565	71.404	235.634
TTO	Trinidad and Tobago	Central America and the Caribbean	WI	WI	0.058	0.222	0.732
TUN	Tunisia	North Africa	CEM	CEM	252.000	696.000	2532.400
TUN	Tunisia	North Africa	CREM	CREM	0.060	0.252	0.906
TUN	Tunisia	North Africa	OR	CO-OR	2.480	5.511	9.093
TUN	Tunisia	North Africa	SC-DR-gas	NG-DR	0.034	0.075	0.124
TUN	Tunisia	North Africa	SC-DR-oil	CO-HF-DR	0.234	0.520	0.858
TUN	Tunisia	North Africa	SC-DR-oil	CO-LF-DR	1.441	3.202	5.283
TUN	Tunisia	North Africa	SC-IND-gas	NG-IND	0.093	0.206	0.340
TUN	Tunisia	North Africa	SC-IND-oil	CO-HF-IND	0.720	1.600	2.640
TUN	Tunisia	North Africa	SC-IND-oil	CO-LF-IND	0.150	0.334	0.551
TUN	Tunisia	North Africa	SC-PP-gas	NG-PP	0.323	0.719	1.186
TUN	Tunisia	North Africa	SC-PP-oil	CO-HF-PP	3.834	8.520	14.058
TUN	Tunisia	North Africa	WASOTH	WASOTH	48.391	186.120	595.585
TUN	Tunisia	North Africa	WI	WI	0.150	0.578	1.851
TUR	Turkey	Middle Eastern States	CEM	CEM	1360.120	3756.521	13668.123
TUR	Turkey	Middle Eastern States	CREM	CREM	0.192	0.854	3.044
TUR	Turkey	Middle Eastern States	NFMP-AL	AL-P	0.525	1.500	2.925
TUR	Turkey	Middle Eastern States	NFMP-AU	GP-L	3.326	475.200	1235.520
TUR	Turkey	Middle Eastern States	NFMP-CU	CU-T	97.283	272.850	1365.780
TUR	Turkey	Middle Eastern States	OR	CO-OR	3.544	7.461	12.311
TUR	Turkey	Middle Eastern States	PISP	PIP	141.102	335.956	2402.087
TUR	Turkey	Middle Eastern States	SC-DR-coal	BC-DR	700.544	1053.450	1506.434
TUR	Turkey	Middle Eastern States	SC-DR-coal	HC-DR	562.391	845.700	1209.351
TUR	Turkey	Middle Eastern States	SC-DR-gas	NG-DR	0.738	1.555	2.565
TUR	Turkey	Middle Eastern States	SC-DR-oil	CO-HF-DR	4.057	8.540	14.091
TUR	Turkey	Middle Eastern States	SC-DR-oil	CO-LF-DR	12.227	25.742	42.474
TUR	Turkey	Middle Eastern States	SC-IND-coal	BC-IND	548.575	824.925	1179.643
TUR	Turkey	Middle Eastern States	SC-IND-coal	HC-IND	220.921	332.213	475.064
TUR	Turkey	Middle Eastern States	SC-IND-gas	NG-IND	0.485	1.021	1.685
TUR	Turkey	Middle Eastern States	SC-IND-oil	CO-HF-IND	4.919	10.355	17.086
TUR	Turkey	Middle Eastern States	SC-IND-oil	CO-LF-IND	0.531	1.117	1.843
TUR	Turkey	Middle Eastern States	SC-PP-coal	BC-L-PP	4066.003	6114.290	8743.435
TUR	Turkey	Middle Eastern States	SC-PP-coal	BC-S-PP	14.783	22.230	31.789
TUR	Turkey	Middle Eastern States	SC-PP-coal	HC-B-PP	389.444	585.630	837.451

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
TUR	Turkey	Middle Eastern States	SC-PP-gas	NG-PP	1.952	4.109	6.779
TUR	Turkey	Middle Eastern States	SC-PP-oil	CO-HF-PP	12.536	26.391	43.545
TUR	Turkey	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.097	0.205	0.339
TUR	Turkey	Middle Eastern States	WASOTH	WASOTH	272.798	1085.325	3607.974
TUR	Turkey	Middle Eastern States	WI	WI	7.859	31.268	103.944
TUV	Tuvalu	Australia, New Zealand & Oceania	CREM	CREM	0.011	0.047	0.178
TUV	Tuvalu	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.020	0.073	0.253
TUV	Tuvalu	Australia, New Zealand & Oceania	WI	WI	0.000	0.000	0.001
TWN	Taiwan (additional to China)	East and Southeast Asia	CEM	CEM	339.961	938.939	3416.335
TWN	Taiwan (additional to China)	East and Southeast Asia	CREM	CREM	1.799	6.479	20.599
TWN	Taiwan (additional to China)	East and Southeast Asia	OR	CO-OR	73.321	162.935	268.842
TWN	Taiwan (additional to China)	East and Southeast Asia	PISP	PIP	100.814	240.033	1716.234
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-DR-gas	NG-DR	0.110	0.245	0.404
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-DR-oil	CO-HF-DR	5.427	12.060	19.899
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-DR-oil	CO-LF-DR	3.785	8.412	13.880
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-IND-coal	HC-IND	328.890	522.047	746.527
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-IND-gas	NG-IND	0.081	0.180	0.297
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-IND-oil	CO-HF-IND	26.710	59.356	97.937
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-IND-oil	CO-LF-IND	0.112	0.249	0.411
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-PP-coal	BC-S-PP	417.442	662.607	947.528
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-PP-coal	HC-B-PP	1395.473	2215.037	3167.503
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-PP-gas	NG-PP	0.881	1.958	3.231
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-PP-oil	CO-HF-PP	19.886	44.190	72.914
TWN	Taiwan (additional to China)	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.069	0.153	0.252
TWN	Taiwan (additional to China)	East and Southeast Asia	WASOTH	WASOTH	114.491	453.195	1561.812
TWN	Taiwan (additional to China)	East and Southeast Asia	WI	WI	41.553	164.479	566.831
TZA	United Republic of Tanzania	Sub-Saharan Africa	ASGM	ASGM	23625.000	33750.000	43875.000
TZA	United Republic of Tanzania	Sub-Saharan Africa	CEM	CEM	46.856	129.413	470.868
TZA	United Republic of Tanzania	Sub-Saharan Africa	CREM	CREM	0.460	1.840	6.440
TZA	United Republic of Tanzania	Sub-Saharan Africa	NFMP-AU	GP-L	13.860	1980.000	5148.000
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.778	1.728	2.851
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-IND-coal	HC-IND	3.059	4.856	6.944
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-IND-gas	NG-IND	0.007	0.015	0.024
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	1.449	3.220	5.313
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	4.111	6.525	9.331
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-PP-gas	NG-PP	0.050	0.112	0.184
TZA	United Republic of Tanzania	Sub-Saharan Africa	SC-PP-oil	CO-HF-PP	0.117	0.260	0.429
TZA	United Republic of Tanzania	Sub-Saharan Africa	WASOTH	WASOTH	35.679	144.785	480.894
TZA	United Republic of Tanzania	Sub-Saharan Africa	WI	WI	0.111	0.450	1.494
UGA	Uganda	Sub-Saharan Africa	ASGM	ASGM	300.000	600.000	900.000
UGA	Uganda	Sub-Saharan Africa	CEM	CEM	20.475	56.550	205.758
UGA	Uganda	Sub-Saharan Africa	CREM	CREM	0.863	3.451	12.078
UGA	Uganda	Sub-Saharan Africa	NFMP-AU	GP-L	0.616	88.000	228.800
UGA	Uganda	Sub-Saharan Africa	WASOTH	WASOTH	24.203	98.213	326.209
UGA	Uganda	Sub-Saharan Africa	WI	WI	0.075	0.305	1.014
UKR	Ukraine	CIS & other European countries	CEM	CEM	261.734	722.883	2630.214
UKR	Ukraine	CIS & other European countries	CREM	CREM	4.825	16.082	53.070
UKR	Ukraine	CIS & other European countries	NFMP-AL	AL-P	0.438	1.250	2.438
UKR	Ukraine	CIS & other European countries	OR	CO-OR	15.612	34.694	57.244
UKR	Ukraine	CIS & other European countries	PISP	PIP	551.356	1312.752	9386.177
UKR	Ukraine	CIS & other European countries	SC-DR-coal	BC-DR	1.985	3.150	4.505
UKR	Ukraine	CIS & other European countries	SC-DR-coal	HC-DR	151.673	240.750	344.273
UKR	Ukraine	CIS & other European countries	SC-DR-gas	NG-DR	1.682	3.738	6.167

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
UKR	Ukraine	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.126	0.280	0.462
UKR	Ukraine	CIS & other European countries	SC-DR-oil	CO-LF-DR	2.980	6.622	10.926
UKR	Ukraine	CIS & other European countries	SC-IND-coal	BC-IND	0.092	0.146	0.209
UKR	Ukraine	CIS & other European countries	SC-IND-coal	HC-IND	138.005	219.056	313.250
UKR	Ukraine	CIS & other European countries	SC-IND-gas	NG-IND	0.613	1.363	2.249
UKR	Ukraine	CIS & other European countries	SC-IND-oil	CO-HF-IND	1.890	4.200	6.930
UKR	Ukraine	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.800	1.778	2.934
UKR	Ukraine	CIS & other European countries	SC-PP-coal	BC-L-PP	0.370	0.588	0.841
UKR	Ukraine	CIS & other European countries	SC-PP-coal	HC-A-PP	388.041	615.938	880.791
UKR	Ukraine	CIS & other European countries	SC-PP-coal	HC-B-PP	1874.431	2975.288	4254.661
UKR	Ukraine	CIS & other European countries	SC-PP-gas	NG-PP	1.891	4.203	6.934
UKR	Ukraine	CIS & other European countries	SC-PP-oil	CO-HF-PP	4.032	8.960	14.784
UKR	Ukraine	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.158	0.352	0.581
UKR	Ukraine	CIS & other European countries	SC-PP-oil	CO-PP	0.009	0.020	0.033
UKR	Ukraine	CIS & other European countries	WASOTH	WASOTH	93.506	361.556	1234.276
UKR	Ukraine	CIS & other European countries	WI	WI	2.694	10.416	35.559
URY	Uruguay	South America	CEM	CEM	15.624	43.152	157.009
URY	Uruguay	South America	CREM	CREM	0.908	3.443	11.893
URY	Uruguay	South America	CSP	CSP-C	24.500	70.000	136.500
URY	Uruguay	South America	NFMP-AU	GP-L	0.604	86.328	224.453
URY	Uruguay	South America	OR	CO-OR	0.885	1.967	3.246
URY	Uruguay	South America	SC-DR-gas	NG-DR	0.003	0.007	0.012
URY	Uruguay	South America	SC-DR-oil	CO-HF-DR	0.324	0.720	1.188
URY	Uruguay	South America	SC-DR-oil	CO-LF-DR	0.660	1.466	2.419
URY	Uruguay	South America	SC-IND-coal	HC-IND	0.213	0.338	0.483
URY	Uruguay	South America	SC-IND-gas	NG-IND	0.002	0.004	0.006
URY	Uruguay	South America	SC-IND-oil	CO-HF-IND	1.052	2.337	3.856
URY	Uruguay	South America	SC-IND-oil	CO-LF-IND	0.024	0.053	0.088
URY	Uruguay	South America	SC-PP-gas	NG-PP	0.001	0.001	0.002
URY	Uruguay	South America	SC-PP-oil	CO-HF-PP	3.181	7.068	11.662
URY	Uruguay	South America	SC-PP-oil	CO-LF-PP	0.384	0.853	1.408
URY	Uruguay	South America	WASOTH	WASOTH	29.823	114.835	390.781
URY	Uruguay	South America	WI	WI	0.093	0.357	1.214
USA	United States	North America	CEM	CEM	697.328	1847.991	27308.397
USA	United States	North America	CREM	CREM	119.747	437.783	1467.862
USA	United States	North America	CSP	CSP-C	382.375	1092.500	2130.375
USA	United States	North America	NFMP-AL	AL-P	54.369	138.080	286.085
USA	United States	North America	NFMP-AU	GP-L	9.579	1368.480	3558.047
USA	United States	North America	NFMP-CU	CU-T	409.960	1149.822	5755.558
USA	United States	North America	NFMP-PB	PB-P	8.111	23.175	45.191
USA	United States	North America	NFMP-ZN	ZN-P	23.747	53.298	95.463
USA	United States	North America	OR	CO-OR	794.171	1671.939	2758.699
USA	United States	North America	PISP	PIP	409.671	922.621	2183.995
USA	United States	North America	SC-DR-coal	BC-DR	54.172	81.461	116.490
USA	United States	North America	SC-DR-coal	HC-DR	206.283	310.200	443.586
USA	United States	North America	SC-DR-gas	NG-DR	21.808	45.911	75.753
USA	United States	North America	SC-DR-oil	CO-HF-DR	27.294	57.460	94.809
USA	United States	North America	SC-DR-oil	CO-LF-DR	145.207	305.698	504.402
USA	United States	North America	SC-IND-coal	BC-IND	437.274	657.555	940.304
USA	United States	North America	SC-IND-coal	HC-IND	2411.556	3626.400	5185.752
USA	United States	North America	SC-IND-gas	NG-IND	11.680	24.590	40.574
USA	United States	North America	SC-IND-oil	CO-HF-IND	35.234	74.176	122.390
USA	United States	North America	SC-IND-oil	CO-LF-IND	16.910	35.600	58.740

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
USA	United States	North America	SC-PP-coal	BC-L-PP	2667.365	4011.075	5735.838
USA	United States	North America	SC-PP-coal	BC-S-PP	10522.508	15823.320	22627.348
USA	United States	North America	SC-PP-coal	HC-A-PP	152.685	229.602	328.331
USA	United States	North America	SC-PP-coal	HC-B-PP	10922.967	16425.514	23488.485
USA	United States	North America	SC-PP-gas	NG-PP	24.187	50.920	84.019
USA	United States	North America	SC-PP-oil	CO-HF-PP	39.732	83.646	138.016
USA	United States	North America	SC-PP-oil	CO-LF-PP	1.558	3.280	5.411
USA	United States	North America	WASOTH	WASOTH	1004.074	4189.493	15096.218
USA	United States	North America	WI	WI	364.410	1520.500	5478.895
UZB	Uzbekistan	CIS & other European countries	ASGM	ASGM	56.250	225.000	393.750
UZB	Uzbekistan	CIS & other European countries	CEM	CEM	181.913	502.425	1828.076
UZB	Uzbekistan	CIS & other European countries	CREM	CREM	1.486	4.955	16.351
UZB	Uzbekistan	CIS & other European countries	NFMP-AU	GP-L	31.185	4455.000	11583.000
UZB	Uzbekistan	CIS & other European countries	NFMP-CU	CU-T	421.176	1181.280	5913.024
UZB	Uzbekistan	CIS & other European countries	NFMP-ZN	ZN-P	221.760	590.400	1450.800
UZB	Uzbekistan	CIS & other European countries	OR	CO-OR	4.382	9.738	16.067
UZB	Uzbekistan	CIS & other European countries	SC-DR-coal	BC-DR	90.342	143.400	205.062
UZB	Uzbekistan	CIS & other European countries	SC-DR-gas	NG-DR	1.896	4.214	6.953
UZB	Uzbekistan	CIS & other European countries	SC-DR-oil	CO-HF-DR	0.018	0.040	0.066
UZB	Uzbekistan	CIS & other European countries	SC-DR-oil	CO-LF-DR	0.914	2.030	3.350
UZB	Uzbekistan	CIS & other European countries	SC-IND-coal	BC-IND	16.585	26.325	37.645
UZB	Uzbekistan	CIS & other European countries	SC-IND-coal	HC-IND	8.351	13.256	18.956
UZB	Uzbekistan	CIS & other European countries	SC-IND-gas	NG-IND	0.641	1.424	2.349
UZB	Uzbekistan	CIS & other European countries	SC-IND-oil	CO-HF-IND	0.009	0.020	0.033
UZB	Uzbekistan	CIS & other European countries	SC-IND-oil	CO-LF-IND	0.098	0.218	0.360
UZB	Uzbekistan	CIS & other European countries	SC-PP-coal	BC-L-PP	157.005	249.214	356.376
UZB	Uzbekistan	CIS & other European countries	SC-PP-gas	NG-PP	1.543	3.429	5.657
UZB	Uzbekistan	CIS & other European countries	SC-PP-oil	CO-HF-PP	2.997	6.660	10.989
UZB	Uzbekistan	CIS & other European countries	SC-PP-oil	CO-LF-PP	0.001	0.002	0.003
UZB	Uzbekistan	CIS & other European countries	SC-PP-oil	CO-PP	0.036	0.080	0.132
UZB	Uzbekistan	CIS & other European countries	WASOTH	WASOTH	40.722	157.460	537.535
UZB	Uzbekistan	CIS & other European countries	WI	WI	0.127	0.489	1.670
VCT	Saint Vincent and the Grenadines	Central America and the Caribbean	CREM	CREM	0.019	0.079	0.264
VCT	Saint Vincent and the Grenadines	Central America and the Caribbean	WASOTH	WASOTH	0.509	1.959	6.465
VCT	Saint Vincent and the Grenadines	Central America and the Caribbean	WI	WI	0.002	0.006	0.020
VEN	Venezuela	South America	ASGM	ASGM	2812.500	5625.000	8437.500
VEN	Venezuela	South America	CEM	CEM	226.800	626.400	2279.160
VEN	Venezuela	South America	CREM	CREM	7.407	28.095	97.057
VEN	Venezuela	South America	NFMP-AL	AL-P	21.105	53.600	111.053
VEN	Venezuela	South America	NFMP-AU	GP-L	2.911	415.800	1081.080
VEN	Venezuela	South America	OR	CO-OR	26.232	58.294	96.185
VEN	Venezuela	South America	SC-DR-gas	NG-DR	0.158	0.350	0.578
VEN	Venezuela	South America	SC-DR-oil	CO-LF-DR	2.633	5.850	9.653
VEN	Venezuela	South America	SC-IND-coal	HC-IND	5.032	7.987	11.422
VEN	Venezuela	South America	SC-IND-gas	NG-IND	1.102	2.450	4.042
VEN	Venezuela	South America	SC-IND-oil	CO-HF-IND	1.958	4.351	7.179
VEN	Venezuela	South America	SC-IND-oil	CO-LF-IND	1.990	4.421	7.295
VEN	Venezuela	South America	SC-PP-gas	NG-PP	0.971	2.157	3.559
VEN	Venezuela	South America	SC-PP-oil	CO-HF-PP	34.439	76.532	126.278
VEN	Venezuela	South America	SC-PP-oil	CO-LF-PP	3.572	7.938	13.098
VEN	Venezuela	South America	WASOTH	WASOTH	219.505	845.220	2876.270

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
VEN	Venezuela	South America	WI	WI	0.682	2.626	8.938
VGB	British Virgin Islands	Central America and the Caribbean	CREM	CREM	0.004	0.017	0.056
VGB	British Virgin Islands	Central America and the Caribbean	WASOTH	WASOTH	0.462	1.779	5.870
VGB	British Virgin Islands	Central America and the Caribbean	WI	WI	0.001	0.006	0.018
VIR	US Virgin Islands	Central America and the Caribbean	CREM	CREM	0.019	0.078	0.262
VIR	US Virgin Islands	Central America and the Caribbean	WASOTH	WASOTH	0.855	3.287	10.847
VIR	US Virgin Islands	Central America and the Caribbean	WI	WI	0.003	0.010	0.034
VNM	Vietnam	East and Southeast Asia	ASGM	ASGM	937.500	3750.000	6562.500
VNM	Vietnam	East and Southeast Asia	CEM	CEM	1320.244	3646.388	13267.402
VNM	Vietnam	East and Southeast Asia	CREM	CREM	26.579	95.740	304.369
VNM	Vietnam	East and Southeast Asia	NFMP-AU	GP-L	1.040	148.500	386.100
VNM	Vietnam	East and Southeast Asia	NFMP-CU	CU-P	27.468	77.040	385.632
VNM	Vietnam	East and Southeast Asia	OR	CO-OR	10.906	24.236	39.989
VNM	Vietnam	East and Southeast Asia	SC-DR-coal	HC-DR	246.362	391.050	559.202
VNM	Vietnam	East and Southeast Asia	SC-DR-oil	CO-HF-DR	1.062	2.360	3.894
VNM	Vietnam	East and Southeast Asia	SC-DR-oil	CO-LF-DR	5.197	11.548	19.054
VNM	Vietnam	East and Southeast Asia	SC-IND-coal	HC-IND	1093.046	1734.994	2481.041
VNM	Vietnam	East and Southeast Asia	SC-IND-gas	NG-IND	0.067	0.149	0.245
VNM	Vietnam	East and Southeast Asia	SC-IND-oil	CO-HF-IND	6.957	15.460	25.509
VNM	Vietnam	East and Southeast Asia	SC-IND-oil	CO-LF-IND	1.035	2.300	3.795
VNM	Vietnam	East and Southeast Asia	SC-PP-coal	HC-A-PP	422.273	670.275	958.493
VNM	Vietnam	East and Southeast Asia	SC-PP-coal	HC-B-PP	43.446	68.963	98.616
VNM	Vietnam	East and Southeast Asia	SC-PP-gas	NG-PP	0.676	1.503	2.480
VNM	Vietnam	East and Southeast Asia	SC-PP-oil	CO-HF-PP	5.670	12.600	20.790
VNM	Vietnam	East and Southeast Asia	SC-PP-oil	CO-LF-PP	0.020	0.044	0.073
VNM	Vietnam	East and Southeast Asia	SC-PP-oil	CO-PP	2.147	4.770	7.871
VNM	Vietnam	East and Southeast Asia	WASOTH	WASOTH	240.244	950.966	3277.243
VNM	Vietnam	East and Southeast Asia	WI	WI	0.747	2.955	10.184
VUT	Vanuatu	Australia, New Zealand & Oceania	CREM	CREM	0.188	0.838	3.141
VUT	Vanuatu	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.615	2.223	7.694
VUT	Vanuatu	Australia, New Zealand & Oceania	WI	WI	0.002	0.007	0.024
WLF	Wallis and Futuna Islands	Australia, New Zealand & Oceania	CREM	CREM	0.015	0.065	0.242
WLF	Wallis and Futuna Islands	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.034	0.122	0.421
WLF	Wallis and Futuna Islands	Australia, New Zealand & Oceania	WI	WI	0.000	0.000	0.001
WSM	Samoa	Australia, New Zealand & Oceania	CREM	CREM	0.190	0.847	3.175
WSM	Samoa	Australia, New Zealand & Oceania	WASOTH	WASOTH	0.449	1.622	5.616
WSM	Samoa	Australia, New Zealand & Oceania	WI	WI	0.001	0.005	0.017
YEM	Yemen	Middle Eastern States	CEM	CEM	110.250	304.500	1107.925
YEM	Yemen	Middle Eastern States	CREM	CREM	0.118	0.524	1.866
YEM	Yemen	Middle Eastern States	OR	CO-OR	0.732	1.627	2.685
YEM	Yemen	Middle Eastern States	SC-DR-oil	CO-LF-DR	1.194	2.654	4.379
YEM	Yemen	Middle Eastern States	SC-IND-oil	CO-LF-IND	0.722	1.604	2.647
YEM	Yemen	Middle Eastern States	SC-PP-gas	NG-PP	0.009	0.021	0.034
YEM	Yemen	Middle Eastern States	SC-PP-oil	CO-HF-PP	14.868	33.040	54.516
YEM	Yemen	Middle Eastern States	SC-PP-oil	CO-LF-PP	0.314	0.698	1.152
YEM	Yemen	Middle Eastern States	SC-PP-oil	CO-PP	2.637	5.860	9.669
YEM	Yemen	Middle Eastern States	WASOTH	WASOTH	21.885	87.071	289.453
YEM	Yemen	Middle Eastern States	WI	WI	0.068	0.271	0.899
ZAF	South Africa	Sub-Saharan Africa	ASGM	ASGM	937.500	3750.000	6562.500
ZAF	South Africa	Sub-Saharan Africa	CEM	CEM	357.420	975.200	4754.100
ZAF	South Africa	Sub-Saharan Africa	CREM	CREM	1.724	6.897	24.140
ZAF	South Africa	Sub-Saharan Africa	NFMP-AL	AL-P	33.894	52.455	70.814
ZAF	South Africa	Sub-Saharan Africa	NFMP-AU	GP-L	100.233	10550.854	23211.878

Country Code	Country Name	Region	Sector Code ¹	Activity Code ¹	Estimate (min)	Emission Estimate, kg	Estimate (max)
ZAF	South Africa	Sub-Saharan Africa	NFMP-CU	CU-P	290.074	813.575	4072.437
ZAF	South Africa	Sub-Saharan Africa	NFMP-ZN	ZN-P	341.649	909.585	2235.139
ZAF	South Africa	Sub-Saharan Africa	OR	CO-OR	7.888	17.528	28.921
ZAF	South Africa	Sub-Saharan Africa	PISP	PIP	106.439	271.857	799.675
ZAF	South Africa	Sub-Saharan Africa	SC-DR-coal	HC-DR	2234.818	3547.330	5072.682
ZAF	South Africa	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	5.274	11.720	19.338
ZAF	South Africa	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	6.675	14.834	24.476
ZAF	South Africa	Sub-Saharan Africa	SC-IND-coal	HC-IND	1438.970	2284.080	3266.234
ZAF	South Africa	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.086	0.190	0.314
ZAF	South Africa	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.890	1.978	3.264
ZAF	South Africa	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	24094.915	36232.955	51813.126
ZAF	South Africa	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.010	0.023	0.038
ZAF	South Africa	Sub-Saharan Africa	WASOTH	WASOTH	246.005	998.282	3315.721
ZAF	South Africa	Sub-Saharan Africa	WI	WI	2.121	8.609	28.593
ZMB	Zambia	Sub-Saharan Africa	ASGM	ASGM	56.250	225.000	393.750
ZMB	Zambia	Sub-Saharan Africa	CEM	CEM	16.538	45.675	166.189
ZMB	Zambia	Sub-Saharan Africa	CREM	CREM	0.451	1.804	6.315
ZMB	Zambia	Sub-Saharan Africa	NFMP-AU	GP-L	0.520	74.250	193.050
ZMB	Zambia	Sub-Saharan Africa	NFMP-CU	CU-P	1529.052	4288.560	21466.848
ZMB	Zambia	Sub-Saharan Africa	OR	CO-OR	0.160	0.356	0.587
ZMB	Zambia	Sub-Saharan Africa	SC-DR-oil	CO-HF-DR	0.153	0.340	0.561
ZMB	Zambia	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.077	0.172	0.284
ZMB	Zambia	Sub-Saharan Africa	SC-IND-coal	HC-IND	0.083	0.131	0.188
ZMB	Zambia	Sub-Saharan Africa	SC-IND-oil	CO-HF-IND	0.459	1.020	1.683
ZMB	Zambia	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.158	0.352	0.581
ZMB	Zambia	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	0.071	0.113	0.161
ZMB	Zambia	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.008	0.018	0.030
ZMB	Zambia	Sub-Saharan Africa	WASOTH	WASOTH	11.490	46.625	154.863
ZMB	Zambia	Sub-Saharan Africa	WI	WI	0.036	0.145	0.481
ZWE	Zimbabwe	Sub-Saharan Africa	ASGM	ASGM	4375.000	8750.000	13125.000
ZWE	Zimbabwe	Sub-Saharan Africa	CEM	CEM	8.269	22.838	83.094
ZWE	Zimbabwe	Sub-Saharan Africa	CREM	CREM	0.453	1.813	6.345
ZWE	Zimbabwe	Sub-Saharan Africa	NFMP-AU	GP-L	1.455	207.900	540.540
ZWE	Zimbabwe	Sub-Saharan Africa	PISP	PIP	0.020	0.048	0.343
ZWE	Zimbabwe	Sub-Saharan Africa	SC-DR-coal	HC-DR	30.524	48.450	69.284
ZWE	Zimbabwe	Sub-Saharan Africa	SC-DR-oil	CO-LF-DR	0.291	0.646	1.066
ZWE	Zimbabwe	Sub-Saharan Africa	SC-IND-coal	HC-IND	19.762	31.369	44.857
ZWE	Zimbabwe	Sub-Saharan Africa	SC-IND-oil	CO-LF-IND	0.041	0.090	0.149
ZWE	Zimbabwe	Sub-Saharan Africa	SC-PP-coal	HC-B-PP	136.647	216.900	310.167
ZWE	Zimbabwe	Sub-Saharan Africa	SC-PP-oil	CO-LF-PP	0.014	0.032	0.053
ZWE	Zimbabwe	Sub-Saharan Africa	WASOTH	WASOTH	3.129	12.696	42.168
ZWE	Zimbabwe	Sub-Saharan Africa	WI	WI	0.010	0.039	0.131

¹ Sector and activity codes are defined in the Glossary; see pages 262–263.

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Acronyms and Abbreviations

AEF	Abated emission factor	GEM	Gaseous elemental mercury (Hg measured following removal of the oxidised compounds by means of KCl-coated denuders and PBM by the sampling air stream)
Al	Aluminium	GMOS	Global Mercury Observation System
AMAP	Arctic Monitoring and Assessment Programme	GOM	Gaseous oxidised mercury (see also RGM)
AMDE	Atmospheric mercury depletion event	Hg	Mercury
AMNet	Atmospheric Mercury Network (US)	Hg ⁰	Elemental mercury
APCD	Air pollution control device	HgII	Inorganic divalent mercury
ASGM	Artisanal and small-scale gold mining	IEA	International Energy Agency
Au	Gold	IPCC	Intergovernmental Panel on Climate Change
BAT	Best Available Technique	ISLSCP	International Satellite Land Surface Climatology
BEP	Best Environmental Practice	LRTAP	UNECE Convention on Long-range Transboundary Air Pollution
Br	Bromine	ΣMeHg	Collective reference to MeHg and DMeHg
CAP	Chlor-alkali production with Hg-technology	MBL	Marine boundary layer
CAMNet	Canadian Atmospheric Monitoring Network	MDN	Mercury Deposition Network (NADP)
CAPMoN	Canadian Air and Precipitation Monitoring Network	MeHg	Monomethyl mercury
CARA	Canadian Clean Air Regulatory Agency	NADP	National Atmospheric Deposition Program (US)
CARIBIC	Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container	NAPRT	North American Pollutant Releases and Transfers (database)
CH ₄	Methane	NCP	Northern Contaminants Program
CIS	Commonwealth of Independent States (the former Soviet Republics, formed during the break-up of the Soviet Union)	NEI	National Emission Inventory
CO	Carbon monoxide	NFM	Non-ferrous metal
CO ₂	Carbon dioxide	NO _x	Nitrogen oxides
Cu	Copper	NPRI	National pollutant release inventory
CVAAS	Cold vapour atomic absorption spectroscopy	O ₃	Ozone
CVAFS	Cold vapour atomic fluorescence spectroscopy	Pb	Lead
DF	Distribution factor	PBM _{2.5}	Particulate bound mercury (particle diameter <2.5 µm)
DGM	Dissolved gaseous mercury	PRI	Pollutant release inventory
DMeHg	Dimethyl mercury	RGM	Reactive gaseous mercury. Over the past five years the term RGM has been replaced by GOM (gaseous oxidised mercury)
DOC	Dissolved organic carbon	SO ₂	Sulphur dioxide
dw	Dry weight	SOP	Standard operating procedure
E-PRTR	European Pollutant Release and Transfer Register	TGM	Total gaseous mercury (non-specified gaseous mercury). TGM represents the total concentration of all forms of gaseous Hg compounds in ambient air
EEA	European Environment Agency	TPM	Total particulate mercury (no defined particle size)
EF	Emission factor	UEF	Unabated emission factor
EMEP	European Monitoring and Evaluation Programme	UNECE	United Nations Economic Commission for Europe
EPA	Environmental Protection Agency (US)	UNEP	United Nations Environment Programme
EU27	The 27 Member States of the European Union	USGS	United States Geological Survey
GAW	Global Atmosphere Watch	VCM	Vinyl chloride monomer
GDP-PPP	Gross Domestic Product at Purchasing Power Parity	Zn	Zinc

Air pollution control device:

ACI	Activated carbon injection
AP	Acid plant
AT	Absorbing tower
BF	Blast furnace
CYC	Cyclone
DS	Dry scrubber
EFF	Electric furnace
ESD	Electrostatic demister
ESP	Electrostatic precipitator (c - cold side, h - hot side)
FB	Fluidised bed
FF	Fabric (bag) filter
FGC	Flue gas conditioning
FGD	Flue gas desulphurisation (w - wet, d - dry)
HgX	Mercury-specific
ISP	Imperial smelting process (Zn)
N	None
PM	Particulate matter
PP	Pelletising plant
PS	Particle scrubber (wet Venturi scrubber - Russia)
RAC	Reactive activated carbon
RT	Mercury-reclaiming tower
RZ	Retort Zn production
SCR	Selective catalytic reduction
SDA	Spray dry absorber
SNCR	Selected non-catalytic reduction
SP	Sinter plant
SP-AZ	Electrostatic artisanal smelting process (Zn)
ST	Spray tower
WGC	Wet gas cleaning
WS	Wet scrubber

Sector codes and (shown inset) their sub-activities

ASGM	Artisanal and small-scale gold production
GP-A	Production of gold (artisanal /small-scale)
CEM	Cement production
CEM	Production of Portland cement
CSITE	Contaminated sites
CSITE	Contaminated sites associated with no longer operational mining activities and closed industrial plants
CSP	Caustic soda production
CSP-C	Chlor-alkali industry using Hg-cell process, based on plant Cl ₂ production capacity
CSP-P	Chlor-alkali industry using Hg-cell process, based on plant Cl ₂ production amount
DENT	Dental use
CREM	Use in dental amalgam, emissions from human cremation
NFMP	Non-ferrous metal production
NFMP-AL	Non-ferrous metal production: Aluminium
AL-P	Production of aluminium from bauxite – primary production
NFMP-AU	Non-ferrous metal production: Large-scale gold production
GP-L	Production of gold from large-scale mining
NFMP-CU	Non-ferrous metal production: Copper
CU-P	Production of refined copper – primary production
CU-T	Production of refined copper – total production (used for some countries where CU-P is not separately quantified)
NFMP-HG	Non-ferrous metal production: Mercury
HG-P	Production of Hg (primary sources)
NFMP-PB	Non-ferrous metal production: Lead
PB-P	Production of refined lead – primary production
PB-T	Production of refined lead – total production (used for some countries where PB-P is not separately quantified)
NFMP-ZN	Non-ferrous metal production: Zinc
ZN-P	Production of refined zinc – primary production
ZN-T	Production of refined zinc – total production (used for some countries where ZN-P is not separately quantified)
OR	Oil refining
CO-OR	Refining of crude oil in oil refineries
PISP	Production of iron and steel
PIP	Primary production of pig iron
PP	Power plants
SC	Stationary fossil fuel combustion

SC-PP	Stationary fossil fuel combustion in (major) power plants	SC-DR-gas	Stationary fossil fuel combustion in other uses (domestic/residential uses, transport, and use in fisheries, agriculture): Natural gas
SC-PP-coal	Stationary fossil fuel combustion in (major) power plants: Coal		
BC-L-PP	Combustion of brown coal (lignite)	NG-DR	Combustion of natural gas
BC-S-PP	Combustion of brown coal (sub-bituminous coals)	WAS	Waste
HC-A-PP	Combustion of hard coal (anthracite)	WASOTH	Waste and other losses due to breakage and disposal in landfill, etc.
HC-B-PP	Combustion of hard coal (bituminous coals)	WI	Incineration of waste (large incinerators)
SC-PP-oil	Stationary fossil fuel combustion in (major) power plants: Oil		
CO-HF-PP	Combustion of heavy fuel oil in (major) power plants		
CO-LF-PP	Combustion of light fuel oil in (major) power plants		
CO-PP	Combustion of crude oil in (major) power plants		
SC-PP-gas	Stationary fossil fuel combustion in (major) power plants: Natural gas		
NG-PP	Combustion of natural gas		
SC-IND	Stationary fossil fuel combustion in industrial uses		
SC-IND-coal	Stationary fossil fuel combustion in industrial uses: Coal		
BC-IND	Combustion of brown coal/lignite		
HC-IND	Combustion of hard coal		
SC-IND-oil	Stationary fossil fuel combustion in industrial uses: Oil		
CO-IND	Combustion of crude oil		
CO-HF-IND	Combustion of heavy fuel oil		
CO-LF-IND	Combustion of light fuel oil		
SC-IND-gas	Stationary fossil fuel combustion in industrial uses: Natural gas		
NG-IND	Combustion of natural gas		
SC-DR	Stationary fossil fuel combustion in other uses (domestic/residential uses, transport, and use in fisheries, agriculture)		
SC-DR-coal	Stationary fossil fuel combustion in other uses (domestic/residential uses, transport, and use in fisheries, agriculture): Coal		
BC-DR	Combustion of brown coal/lignite		
HC-DR	Combustion of hard coal		
SC-DR-oil	Stationary fossil fuel combustion in other uses (domestic/residential uses, transport, and use in fisheries, agriculture): Oil		
CO-DR	Combustion of crude oil		
CO-HF-DR	Combustion of heavy fuel oil		
CO-LF-DR	Combustion of light fuel oil		

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