UNEP

AMAP

# Technical Background Report for the Global Mercury Assessment

# 2013

UNEP

AMAP

# Technical Background Report for the Global Mercury Assessment

2013

*Citation:* AMAP/UNEP, 2013. Technical Background Report for the Global Mercury Assessment 2013. Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland. vi + 263 pp.

*Disclaimer*

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations Environment Programme concerning the legal status of any country, territory, city or area or of its authorities, or concerning delimitation of its frontiers or boundaries. Moreover, the views expressed do not necessarily represent the decision or the stated policy of the United Nations Environment Programme, nor any of the donors mentioned below, nor does citing of trade names or commercial processes constitute endorsement.

*Reproduction*

This publication may be reproduced in whole or in part and in any form for educational or non-profit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. Material in this report can be freely quoted or reprinted. AMAP and UNEP would appreciate receiving a copy of any publication that uses this report as a source.

No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from the Arctic Monitoring and Assessment Programme or the United Nations Environment Programme.

*Funding*

The work has been funded by the Governments of Canada, Denmark, Japan, Norway, and Sweden, and by the Nordic Council of Ministers and the European Union.

*Produced by*

Arctic Monitoring and Assessment Programme
AMAP Secretariat
Gaustadalléen 21
N-0349 Oslo
Norway
Tel. +47 22 95 83 40
Fax +47 22 60 44 27
amap@amap.no

and

United Nations Environment Programme (UNEP)
Division of Technology, Industry and Economics (DTIE)
Chemicals Branch
International Environment House
11-13, Chemin des Anémones
CH-1219 Châtelaine (Geneva)
Switzerland
Tel: +41 (0) 22 917 81 85
Fax: +41 (0) 22 797 34 60
Email : metals.chemicals@unep.org
http://unep.org/hazardoussubstances/

The report can be found on the AMAP website *www.amap.no* and UNEP Chemicals Branch's website: *http://www.unep.org/hazardoussubstances/Mercury/Informationmaterials/ReportsandPublications/tabid/3593/Default.aspx*

AMAP/UNEP promote environmentally sound practices globally and in their own activities. This publication is printed on paper from environmentally-managed forests, using vegetable-based inks and other eco-friendly practices. Our distribution policy aims to reduce AMAP/UNEP's carbon footprint.

*Scientific, technical and linguistical editing*
Carolyn Symon (carolyn.symon@btinternet.com)

*Lay-out and technical production*
Burnthebook Design, Derby DE24 8HR, United Kingdom (burnthebook.co.uk)

*Printing*
Narayana Press, Gylling, DK-8300 Odder, Denmark (www.narayanapress.dk) a swan-labelled printing company, 541 562

*Cover photo:*
Mercury vaporization and silver fusion stove in a Mexican silver mine. By unidentified author, published on Magasin Pittoresque, Paris, 1844. (www.shutterstock.com)

## Acknowledgements

UNEP and AMAP would like to express their appreciation to all the experts that have contributed to this work. Particular thanks are given to chapter lead authors and members of the UNEP/AMAP Expert Group. A list of contributing experts is provided below; chapter authors are highlighted in bold.

Elke Bieber, Lars Petter Bingh, Paul Bunyana, **Sergio Cinnirella**, **Ashu Dastoor**, Leila Devia, Richard Derwent, **Ralf Ebinghaus**, Xinbin Feng, **Lynne Gratz**, Tomas Gustafsson, Petra Hagström, **Ian Hedgecock**, **Milena Horvat**, Yoshihiro Inoue, Dan Jaffe, Gerard S. Jennings, Wojciech Jozewicz, **Karin Kindbom**, Hans Kock, **David Kocman**, Allan Kolker, Artemis Kostareli, Ragini Kumari, Joy Leaner, Jacob Maag, Otávio Luiz Gusso Maioli, Alistar J. Manning, Vagner Maringolo, **Robert Mason**, Peter Maxson, **John Munthe**, Peter Nelson, **Peter Outridge**, Jozef Pacyna, **Nicola Pirrone**, Eric Prestbo, Deepak Pudasainee, Michel Schuetze, Andreas Schwerin, Gregory Scott, Yong Chil Seo, Lesley Sloss, Gustavo Solorzano, Gerard T. Spain, **Francesca Sprovieri**, **Frits Steenhuisen**, Madeleine Strum, Elsie Sunderland, Kyrre Sundseth, Noriyuki Suzuki, **Kevin Telmer**, **Oleg Travnikov**, Shuxiao Wang, Andreas Weigelt, **Simon Wilson**, **Katarina Yaramenka**

# Contents

# 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

**Authors:** Simon Wilson, John Munthe, Peter Outridge, Robert Mason

**Contributor:** Elsie Sunderland

## 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 can 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.

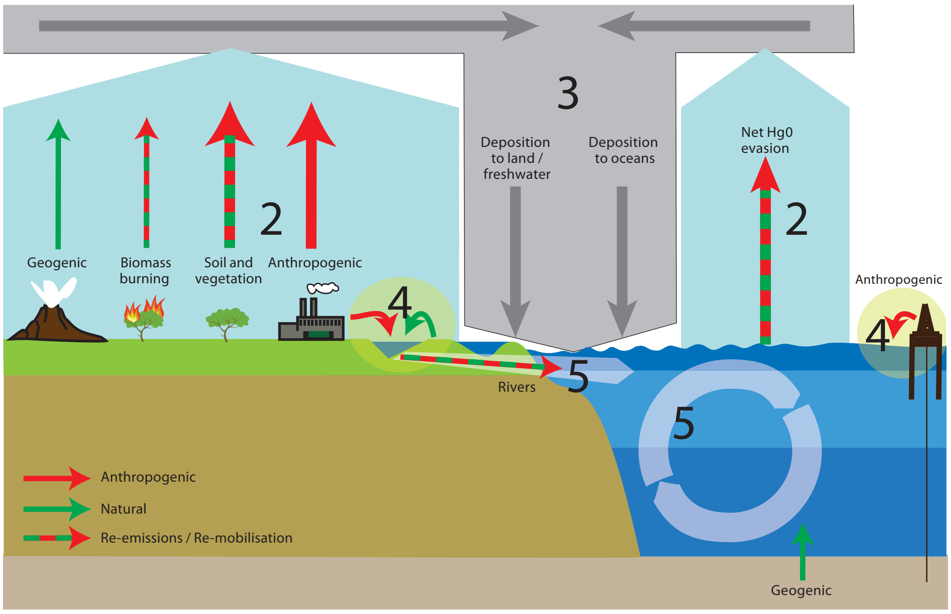


Figure 1.1. Components of the global mercury cycle as addressed in this report. Numbers refer to the chapters of this report.

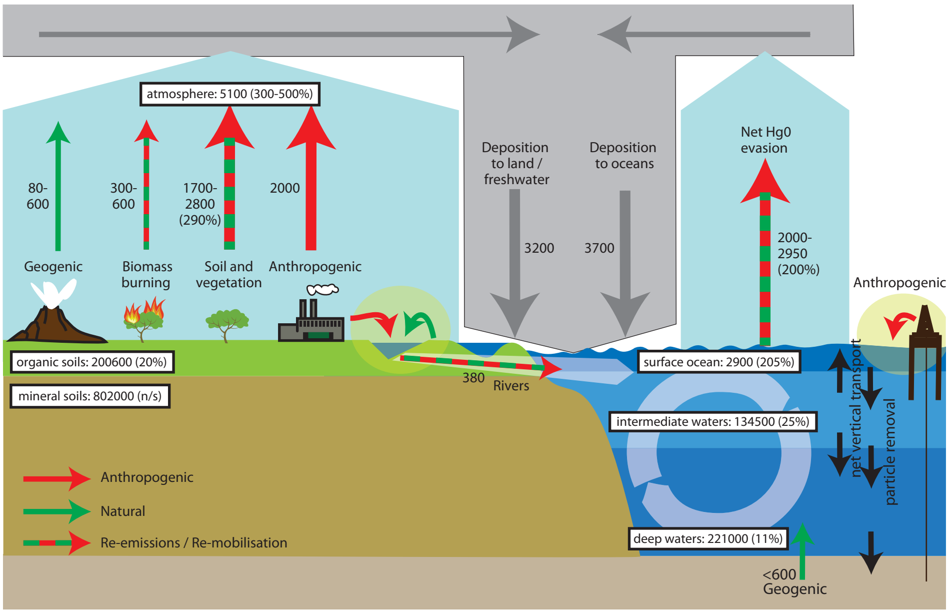


Figure 1.2. The global mercury budget. Source: adapted from Mason et al. (2012). Total inventories (numbers in white boxes) are in tonnes, and fluxes in tonnes per year. The percentage values in brackets are the estimated increases in inventories in the past 100 years due to anthropogenic activities.

## 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 HgII (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 ~ 675 ± 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

**Authors:** Simon Wilson, Karin Kindbom, Katarina Yaramenka, Frits Steenhuisen, Kevin Telmer, John Munthe

**Contributing authors:** Leila Devia, Tomas Gustafsson, Wojciech Jozewicz, Ragini Kumari, Joy Leaner, Jacob Maag, Otávio Luiz Gusso Maioli, Peter Maxson, Peter Nelson, Jozef Pacyna, Deepak Pudasainee, Yong Chil Seo, Lesley Sloss, Gustavo Solorzano, Madeleine Strum, Kyrre Sundseth, Noriyuki Suzuki

**Contributors:** Lars Petter Bingh, Paul Bunyana, Sergio Cinnirella, Petra Hagström, Yoshihiro Inoue, Allan Kolker, Artemis Kostareli, Vagner Maringolo, Nicloa Pirrone, Gregory Scott, Shuxiao Wang

## 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 current[1] 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 2000[2] 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/$SO_2$ (mercury / sulphur dioxide) ratio, with ratios of $1.18 \times 10^{-5}$, $1.16 \times 10^{-5}$ and $5.88 \times 10^{-6}$ 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/m$^2$/d near the equator to ~3 ng/m$^2$/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/m$^2$/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/m$^2$/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.

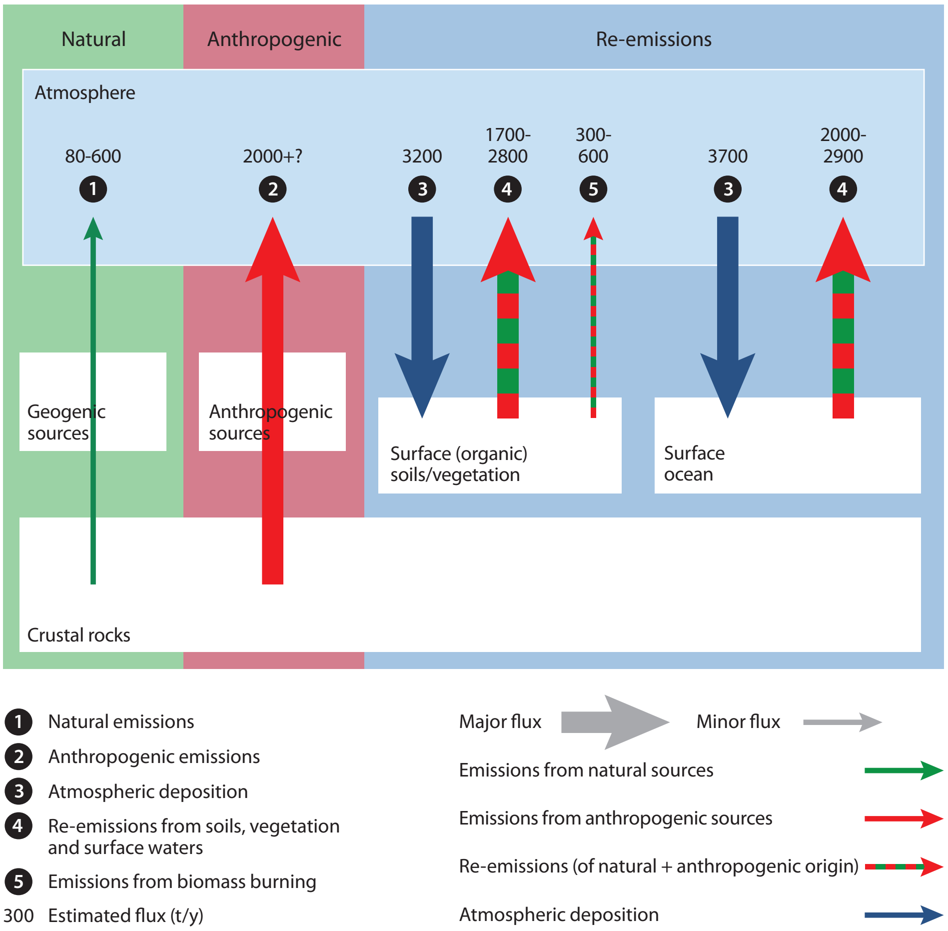


Figure 2.1. Schematic illustration of the main sources of mercury to the atmosphere showing natural, anthropogenic and re-emission components, and fluxes between the atmosphere and various surface environmental compartments. Flux estimates are in t/y as derived from Mason et al. (2012) (see also Figure 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 inventory[3] 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 estimates[4].

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 factor[5] 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.

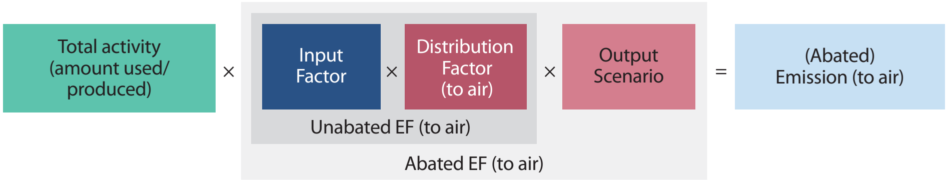


Figure 2.3. Method used to calculate emissions estimates in the UNEP Toolkit approach.

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

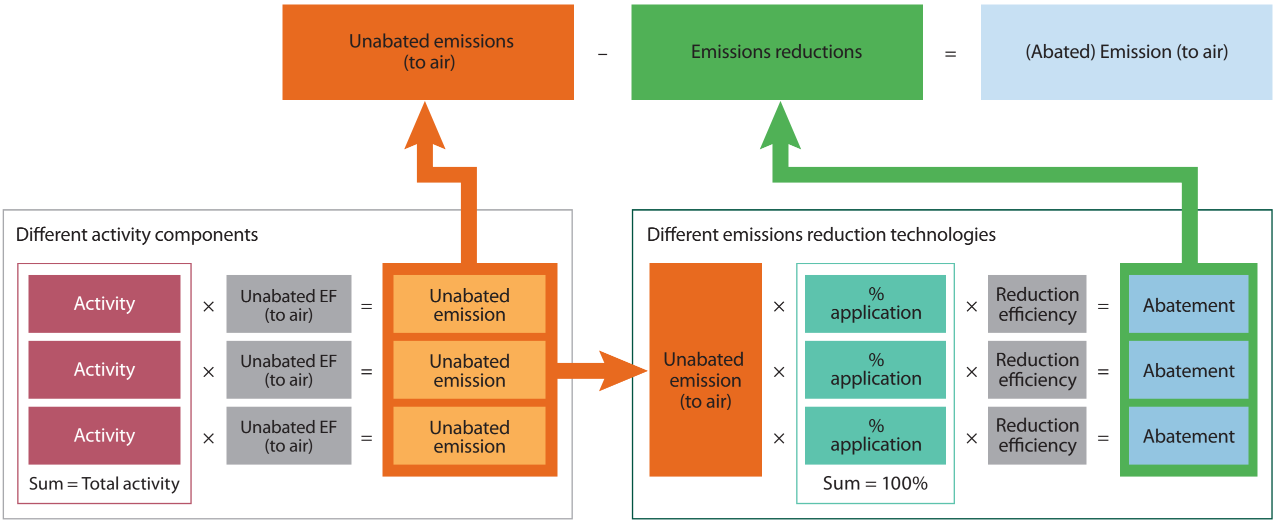


Figure 2.4. Method used to calculate emissions estimates (to air) for the 2010 inventory estimates.

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 aluminium[6].
- 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.

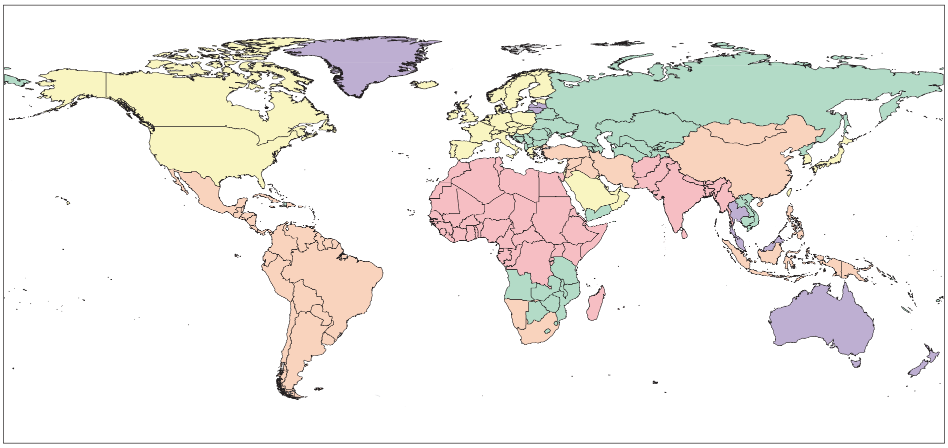


Figure 2.5 Regional groupings applied in the definition of technology profiles associated with mercury emissions from energy and industrial sources.

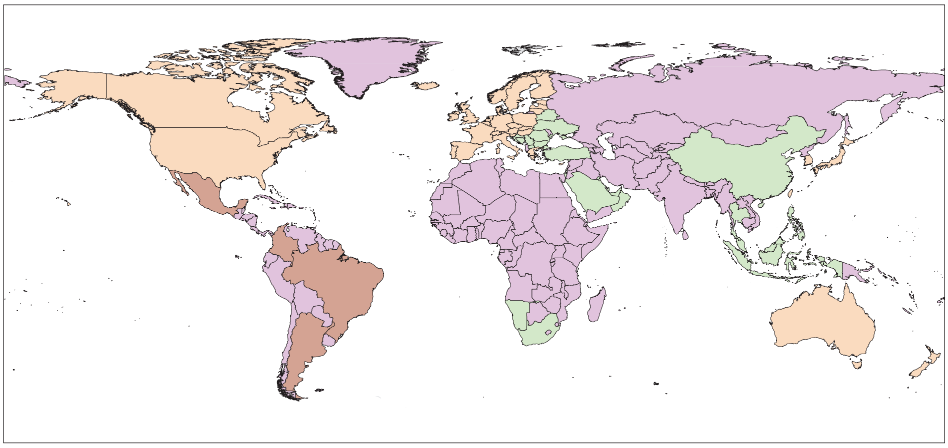


Figure 2.6. Regional groupings applied in the definition of waste management profiles associated with mercury emissions from intentional-use sectors.

- 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)<br>Coal combustion (SC-PP-coal) | Combustion of hard coal (anthracite) (HC-A-PP)<br>Combustion of hard coal (bituminous coals) (HC-B-PP)<br>Combustion of brown coal (sub-bituminous coals)(BC-S-PP)<br>Combustion of brown coal (lignite)(BC-L-PP) | By-product | 1A1a Public electricity and heat production<br>[Sum of emissions from all fuels. Can include waste incinerated for energy recovery.] |
| Stationary fossil fuel combustion (SC) in (major) power plants (SC-PP)<br>Oil combustion (SC-PP-oil) | Combustion of crude oil (CO-PP)<br>Combustion of heavy fuel oil (CO-HF-PP)<br>Combustion of light fuel oil (CO-LF-PP) | By-product | |
| Stationary fossil fuel combustion (SC) in (major) power plants (SC-PP)<br>Natural gas combustion (SC-PP-gas) | Combustion of natural gas (NG-PP) | By-product | |
| Stationary fossil fuel combustion (SC) in industrial uses (SC-IND)<br>Coal combustion (SC-IND-coal) | Combustion of hard coal (HC-IND)<br>Combustion of brown coal/lignite (BC-IND) | By-product | Stationary combustion in manufacturing industries and construction:<br>1A2a Iron and steel<br>1A2b Non-ferrous metals<br>1A2c Chemicals<br>1A2d Pulp, Paper and Print<br>1A2e Food processing, beverages and tobacco<br>1A2fi Other<br>[Sum of emissions from all fuels] |
| Stationary fossil fuel combustion (SC) in industrial uses (SC-IND)<br>Oil combustion (SC-IND-oil) | Combustion of crude oil (CO-IND)<br>Combustion of heavy fuel oil (CO-HF-IND)<br>Combustion of light fuel oil (CO-LF-IND) | By-product | |
| Stationary fossil fuel combustion (SC) in industrial uses (SC-IND)<br>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)<br>Coal combustion (SC-DR-coal) | Combustion of hard coal (HC-DR)<br>Combustion of brown coal/lignite (BC-DR) | By-product | 1A4ai Commercial / institutional: Stationary;<br>1A4bi Residential: Stationary plants;<br>1A4ci Agriculture/Forestry/Fishing: Stationary<br>[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)<br>Oil combustion (SC-DR-oil) | Combustion of crude oil (CO-DR)<br>Combustion of heavy fuel oil (CO-HF-DR)<br>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)<br>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<br>1B1b Solid fuel transformation<br>1B1c Other fugitive emissions from solid fuels<br>1A2a Iron and steel, stationary combustion<br>[2C1 Includes also secondary steel.<br>1B1b/c includes coke production<br>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<br>1A2b Non-ferrous metals<br>[Includes also secondary aluminium.<br>Emissions may be classified as process emissions (2C3) and/or emissions from stationary combustion (1A2b).] |
| | Production of refined copper – primary production (CU-P)<br>Production of refined copper – total production (CU-T) (used for some countries where CU-P is not separately quantified) | By-product | 2C5a Copper production<br>2C5e Other metal production<br>1A2b Non-ferrous metals, stationary combustion<br>[Includes also secondary copper. May be reported included in a sum for all non-ferrous metals in 2C5e.<br>Emissions may be classified as process emissions (2C5a/e) and/or emissions from stationary combustion (1A2b).] |

| | | | |
|---|---|---|---|
| | Production of refined lead – primary production (PB-P)<br>Production of refined lead – total production (PB-T) (used for some countries where PB-P is not separately quantified) | By-product | 2C5b Lead production<br>2C5e Other metal production<br>1A2b Non-ferrous metals, stationary combustion<br>[Includes also secondary lead. May be reported included in a sum for all non-ferrous metals in 2C5e.<br>Emissions may be classified as process emissions (2C5b/e) and/or emissions from stationary combustion (1A2b).] |
| | Production of refined zinc – primary production (ZN-P)<br>Production of refined zinc – total production (ZN-T) (used for some countries where ZN-P is not separately quantified) | By-product | 2C5d Zinc production<br>2C5e Other metal production<br>1A2b Non-ferrous metals, stationary combustion<br>[Includes also secondary zinc. May be reported included in a sum for all non-ferrous metals in 2C5e.<br>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<br>1A2b Non-ferrous metals<br>[May be included in a sum for all non-ferrous metals in 2C5e.<br>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<br>1A2b Non-ferrous metals, stationary combustion<br>[May be included in a sum for all non-ferrous metals in 2C5e.<br>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<br>[May include emissions from all/other nonferrous metals production.] |
| Cement production (CEM) | Production of Portland cement (CEM) | By-product | 2 A 1 Cement production<br>1 A 2 f i Other stationary combustion<br>[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<br>[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<br>1B2ai Exploration, production, transport<br>1B2aiv Refining / storage<br>1B2c Venting and flaring<br>[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<br>[6Cc may include uncontrolled waste incineration.<br>Waste incinerated for energy recovery may be included in 1A1a<br>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)<br>[Industrial waste incineration and incineration of sewage sludge are not included in the 2010 emissions estimates.] | Intentional use | 3D3 Other product use<br>6Ca Clinical waste incineration<br>(6Cb Industrial waste incineration)<br>6Ce Small scale waste burning<br>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 production[7]
- 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.

### 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

---

[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.

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 ± 50% to ± 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 ± 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 regions[8].

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

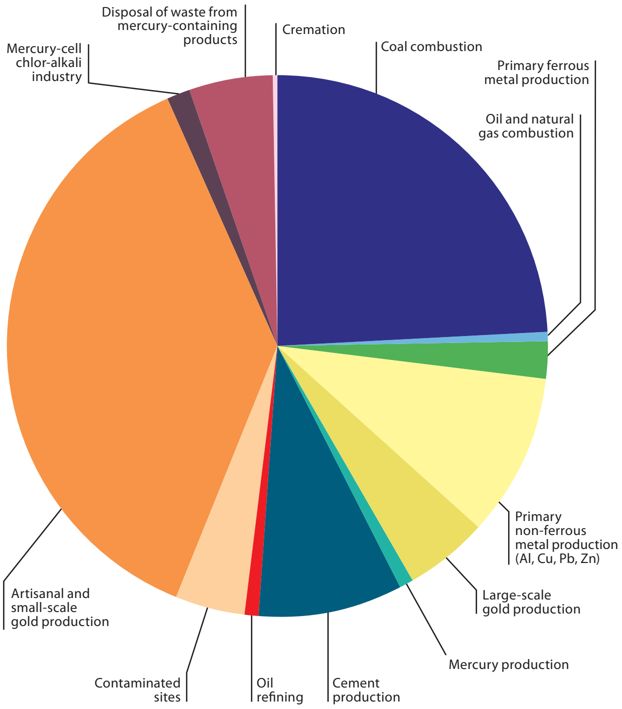


Figure 2.7. Proportions of global anthropogenic mercury emissions to air in 2010 from different sectors.

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,

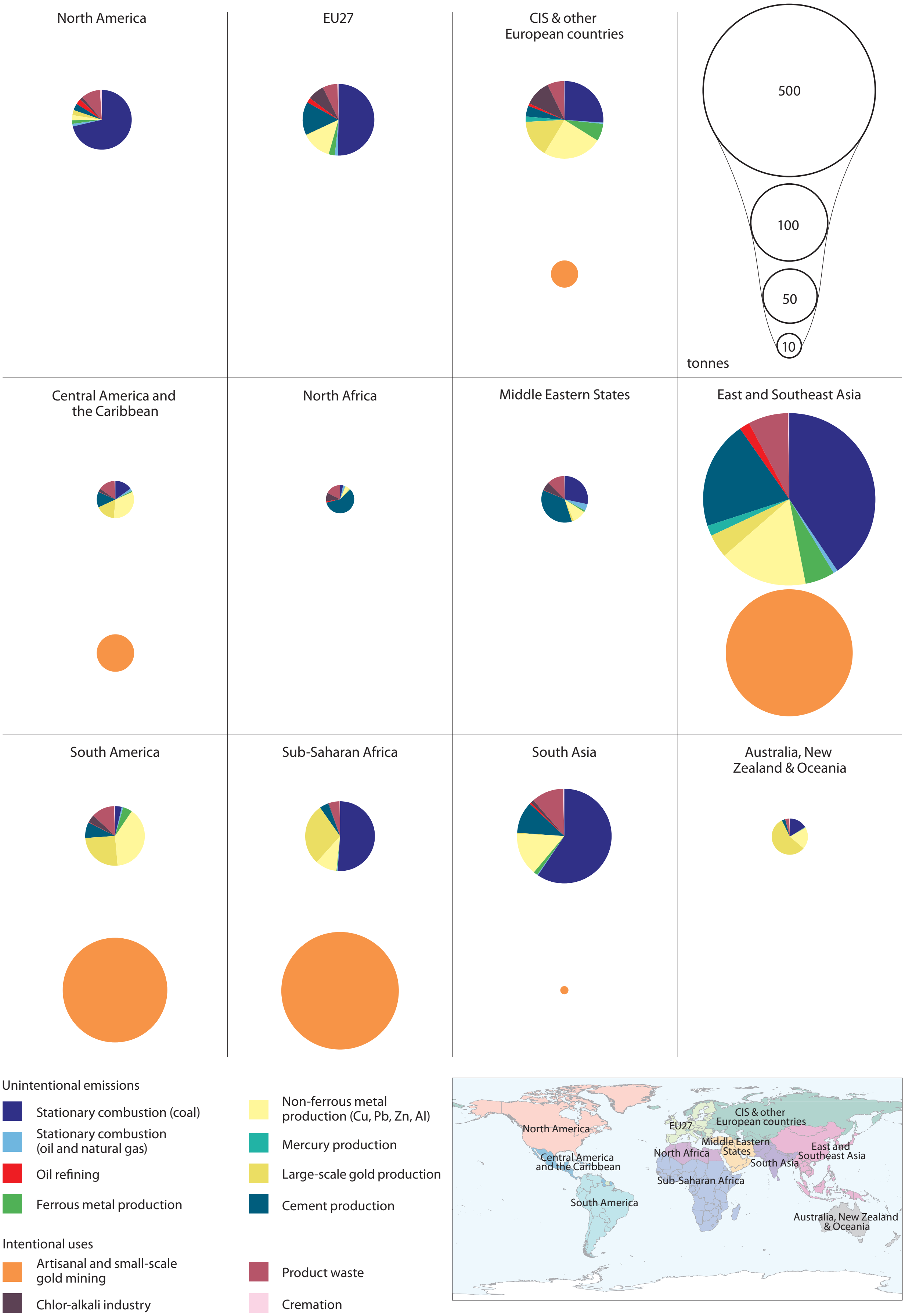


Figure 2.8. Regional pattern of global anthropogenic mercury emissions to air in 2010 from different sectors (does not include emissions from contaminated sites).

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, 1A2fi, 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

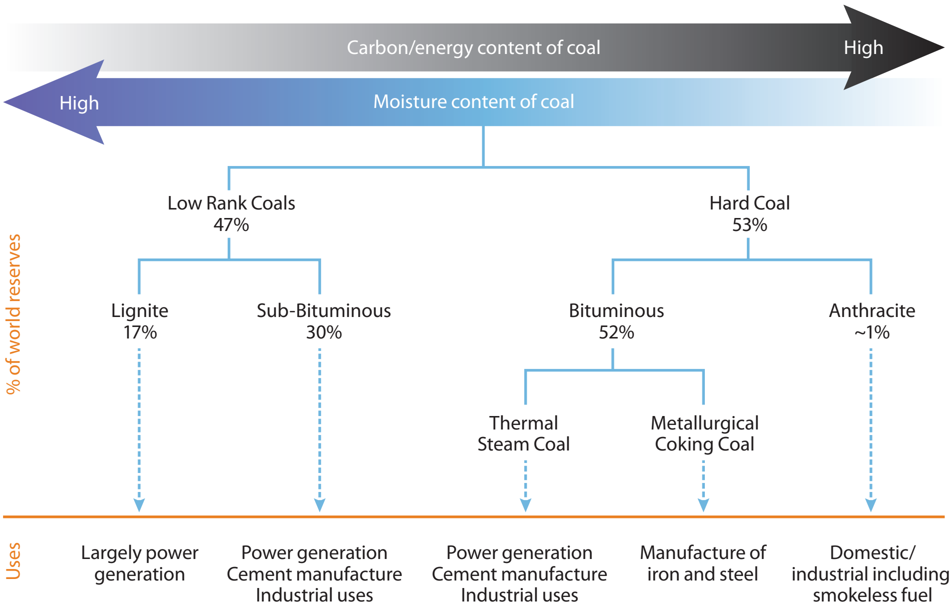


Figure 2.9. Coal types and their uses. Source: after World Coal Association.

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. ± 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 (± 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 recyled 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).

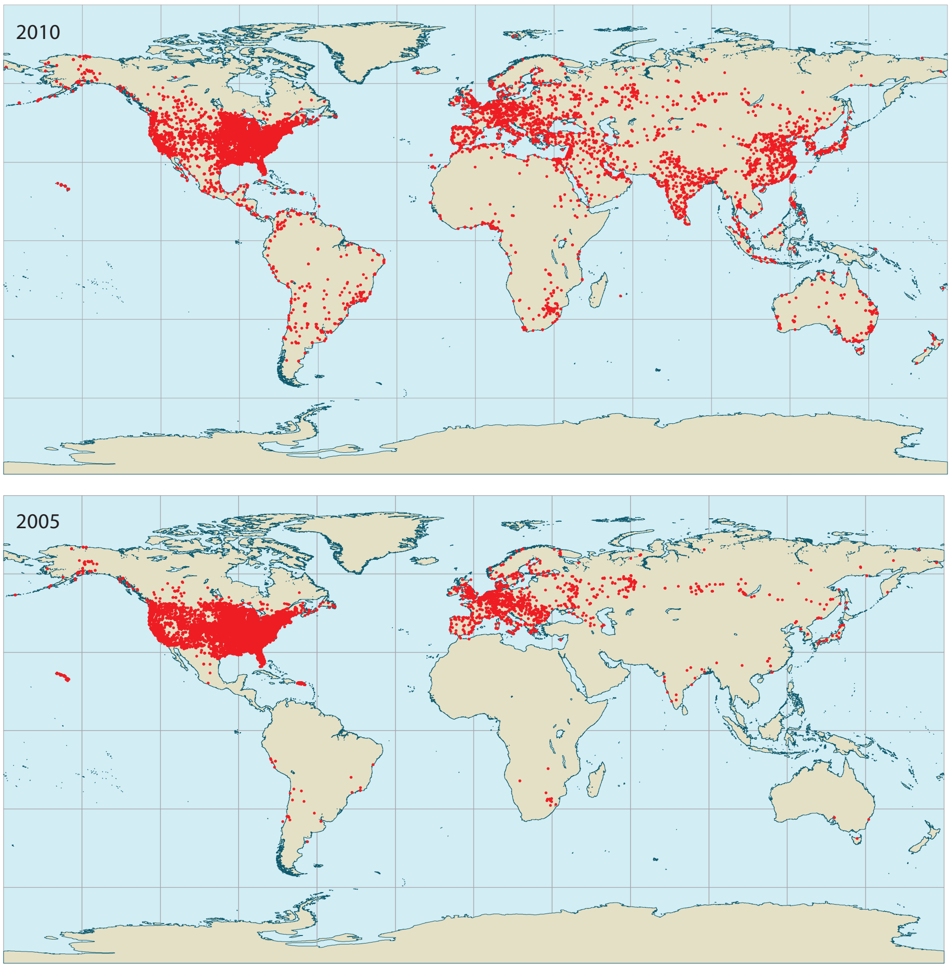


Figure 2.10. Maps showing the increase in the number of mercury point sources utilised in the geospatial distribution of the 2010 global inventory (above) compared with those utilised in the 2005 global inventory (below) spatial distribution work.

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 county'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.

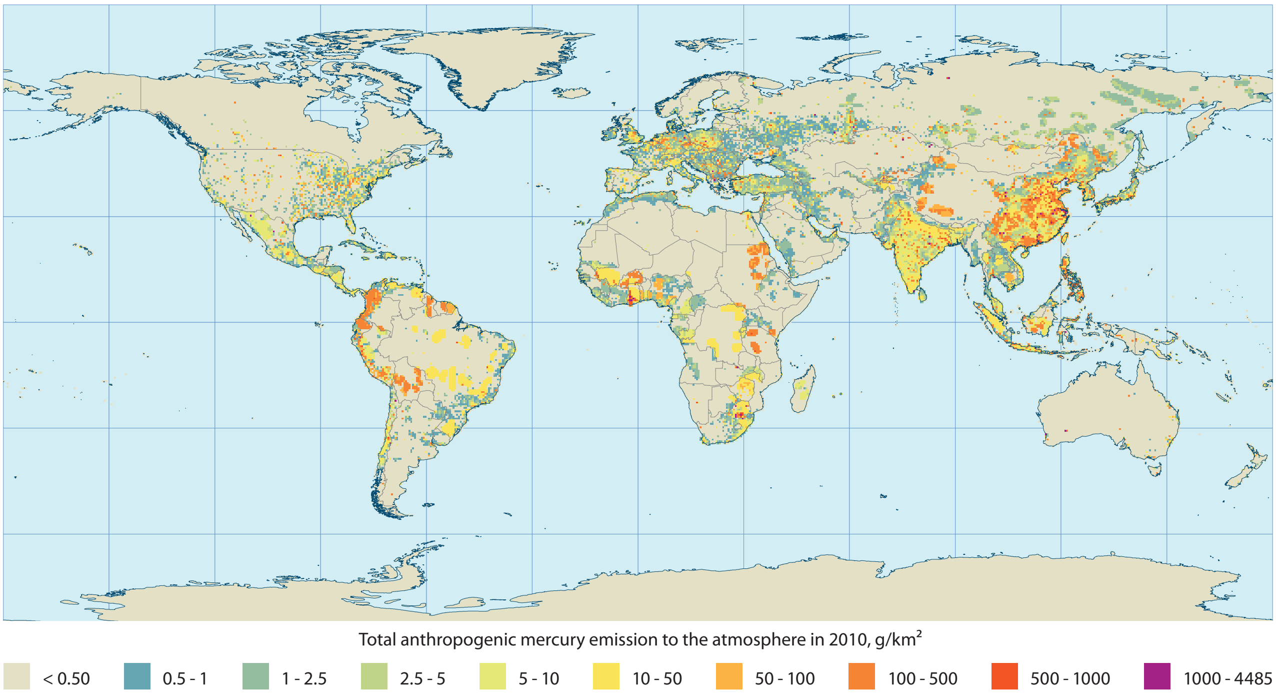


Figure 2.11. The geospatially distributed 2010 global inventory of anthropogenic mercury emissions to air (does not include emissions from contaminated sites).

## 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

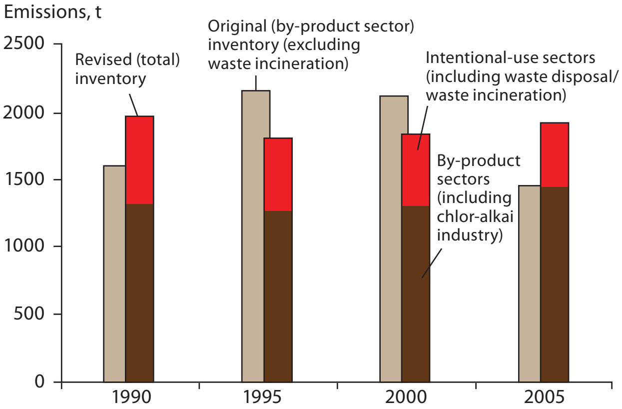


Figure 2.12. Revised estimates of total global anthropogenic mercury emissions to air from by-product and intentional-use sectors for the period 1990–2005, showing the effect of re-calculation using the 2005 methodology. Source: AMAP (2010).

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?

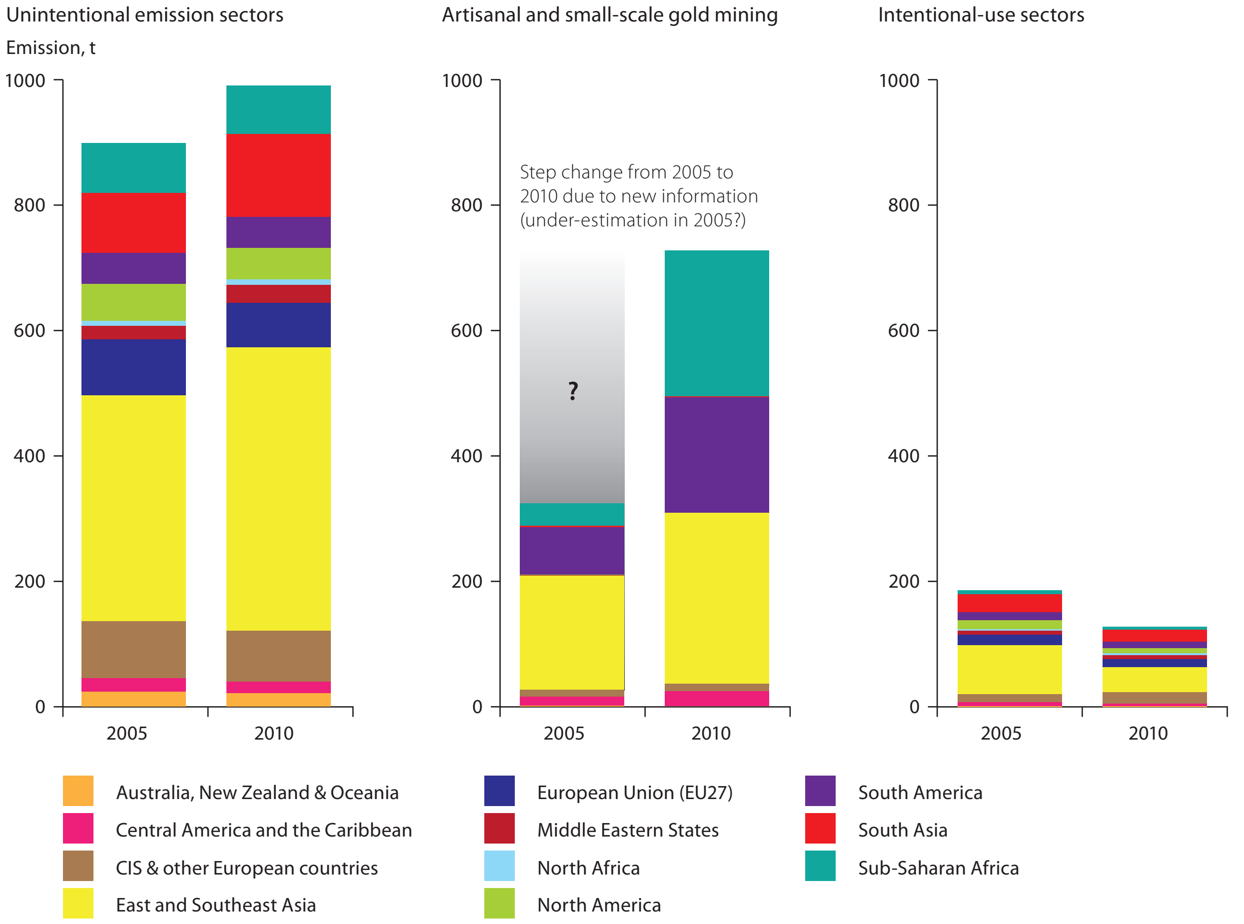


Figure 2.13. Comparison of 2005 and 2005 estimates of emissions to air from different regions, based on application of the 2010 inventory methodology. Unintentional emission sectors: Coal burning, ferrous- and non-ferrous (Au, Cu, Hg, Pb, Zn) metal production, cement production. Intentional-use sectors: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

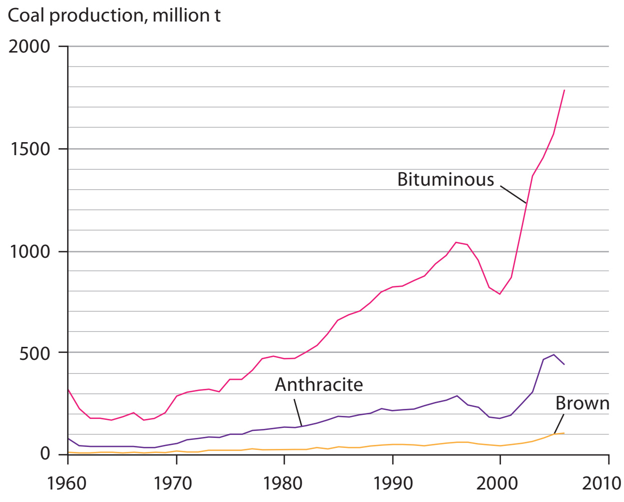


Figure 2.14. Trends in coal production in China. Source: Based on International Energy Agency data.

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<br>(Cu, Pb, Zn, Au, Hg) | | | Waste<br>(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 Amerca, 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) emissons 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.

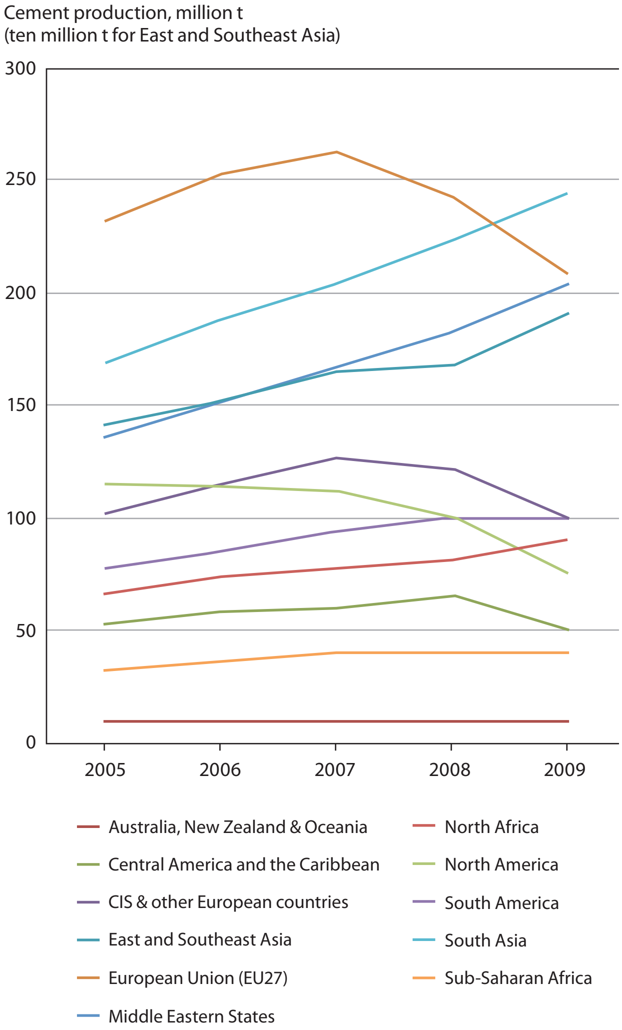


Figure 2.15. Trends in cement production. Note: different units for East and Southeast Asia. Source: United States Geological Survey.

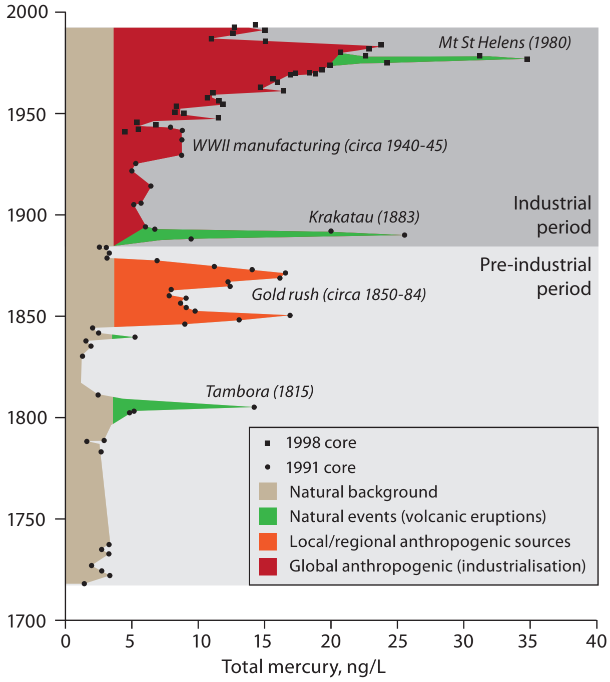


Figure 2.16. Ice core record of deposition from Wyoming, USA. Source: after Schuster et al. (2002).

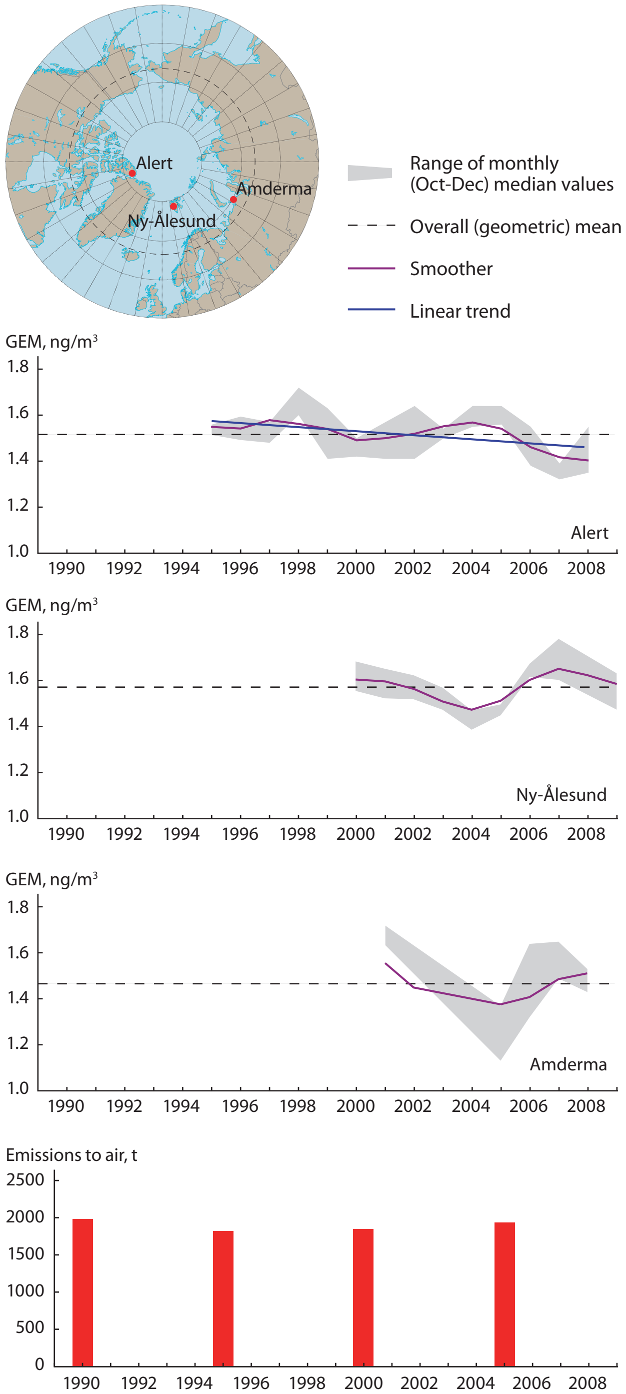


Figure 2.17. Trends in emissions (see Figure 2.12) and observed gaseous elemental mercury concentrations at Arctic background air monitoring sites. Source: after AMAP (2011).

## 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. ± 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 indicted 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 confiidence 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

**Authors:** Nicola Pirrone, Sergio Cinnirella, Ashu Dastoor, Ralf Ebinghaus, Lynne Gratz, Ian Hedgecock, Francesca Sprovieri, Oleg Travnikov

**Contributing authors:** Elke Bieber, Richard Derwent, Xinbin Feng, Dan Jaffe, Gerard S. Jennings, Hans Kock, Alistar J. Manning, Eric Prestbo, Maik Schuetze, Andreas Schwerin, Gerard T. Spain, Andreas Weigelt

## 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 GOM[9] 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/m$^3$ (~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/m$^3$), 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 lead 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 $PBM_{2.5}$;<br>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<br>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 at 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).

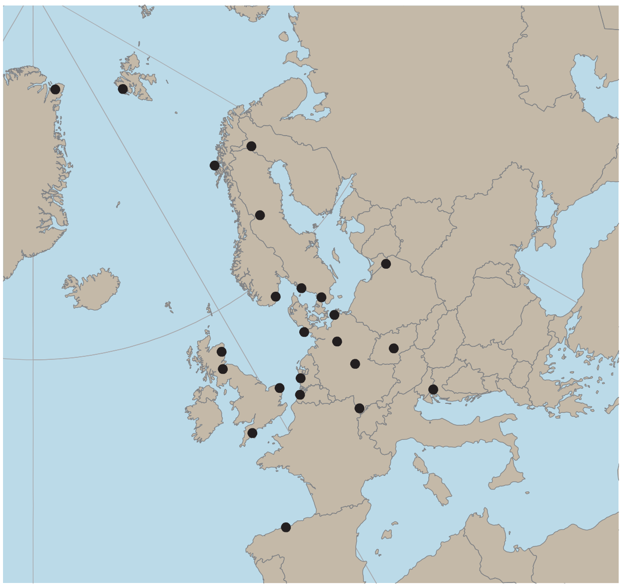


Figure 3.1 Mercury measurement sites within the EMEP network. Source: after Travnikov et al. (2012).

## 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

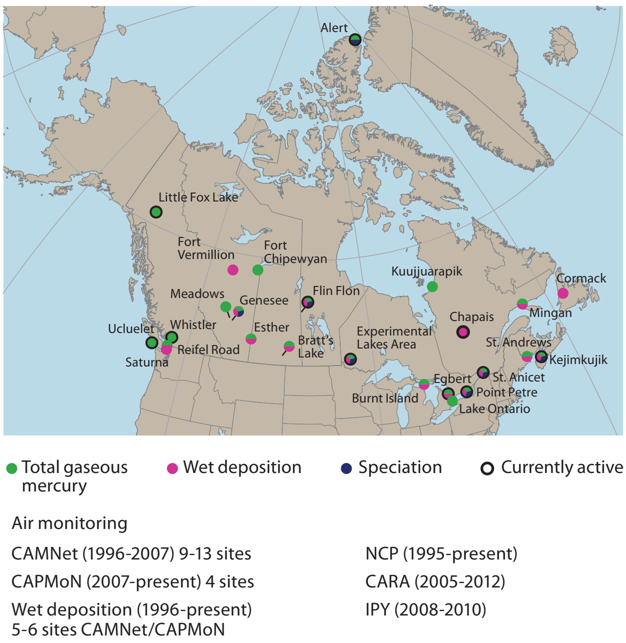


Figure 3.2 Locations of the past and current atmospheric mercury monitoring sites and networks across Canada. Source: Environment Canada.

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 $PBM_{2.5}$ 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 to ensure that atmospheric Hg measurements collected on a network-scale are highly comparable and applicable to the modelling and policy communities.

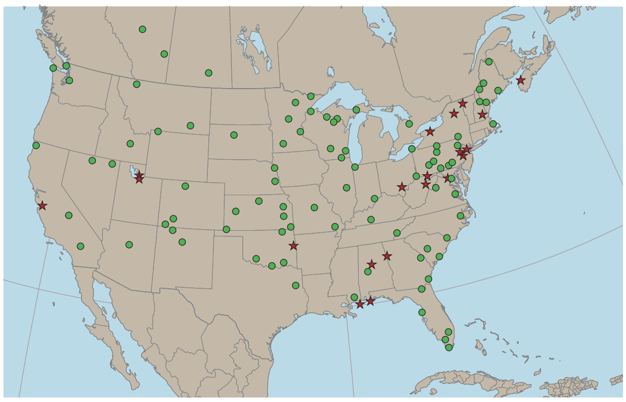


Figure 3.3 NADP Mercury Deposition Network Sites (MDN, http://nadp.isws.illinois.edu/MDN/) and NADP Air Mercury Network Sites AMNet ambient air mercury speciation sites (http://nadp.isws.illinois.edu/amn/). Source: National Atmospheric Deposition Program and Prestbo et al. (2011).

### 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 $PBM_{2.5}$ (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 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 'Zepplin' 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 Zepplin (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.

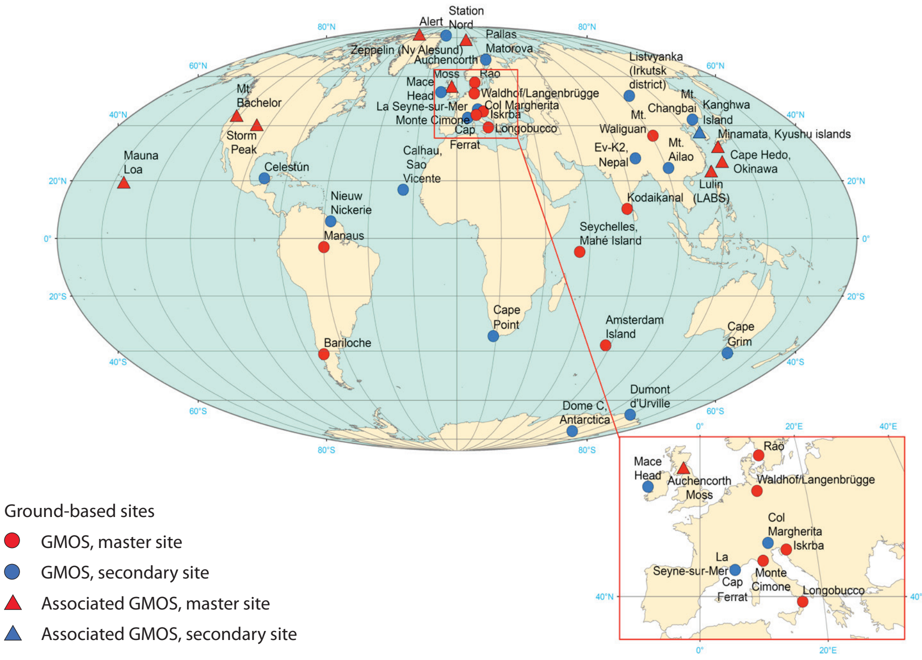


Figure 3.4 Ground-based monitoring sites participating in the GMOS programme (www.gmos.eu). GMOS Master sites are those where GEM, GOM, and $PBM_{2.5}$ are continuously measured and Hg in rainfall measured where appropriate. Secondary GMOS sites are those where only TGM and Hg in precipitation are continuously 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 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/m$^3$ in 1996 to 1.40 ng/m$^3$ in 2011. They showed a statistically significant negative (downward) trend of -0.027 ± 0.01 ng/m$^3$/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).

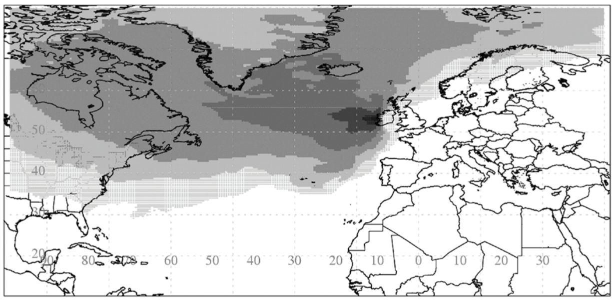


Figure 3.5 A composite of the back-attribution plots for Mace Head, Ireland for all air masses assigned to the baseline category during 1998, with the pixel shading showing the relative contribution to the air concentration at Mace Head, Ireland from the emissions of an inert tracer at that location.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

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/m$^3$/y. When cruise measurements from the southern hemisphere were included in this calculation, the observed declining trend was -0.035 ± 0.005 ng/m$^3$/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/m$^3$/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/m$^3$ (10% and 90% percentiles). The minimum and maximum daily average concentrations were 1.1 and 3.1 ng/m$^3$, respectively. The three-year median concentration was 1.63 ng/m$^3$, similar to the northern hemispheric background concentration of 1.7 ng/m$^3$ (Ebinghaus et al., 2011). The median TPM concentration (6.74 pg/m$^3$) was about five times higher than the median GOM concentration (1.27 pg/m$^3$). $PBM_{2.5}$ 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 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.

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 |

### 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,

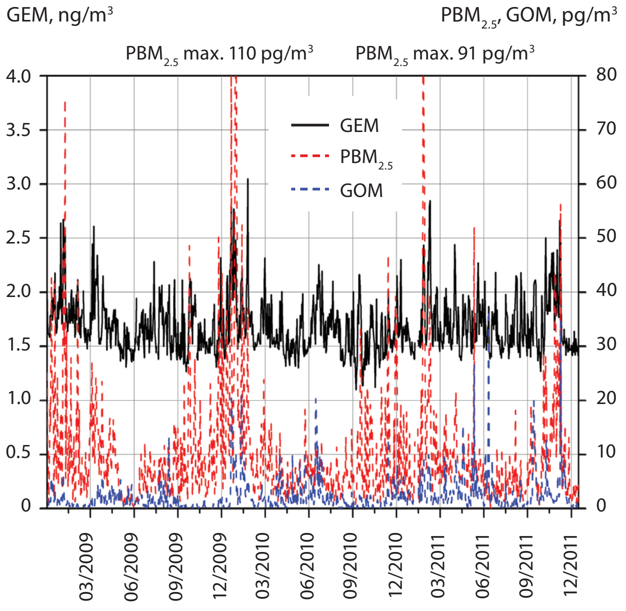


Figure 3.6 Daily averages for GEM, $PBM_{2.5}$, and GOM from January 2009 to December 2011 at the German EMEP station and measurement site 'Waldhof'. Source: Weigelt et al. (2012).

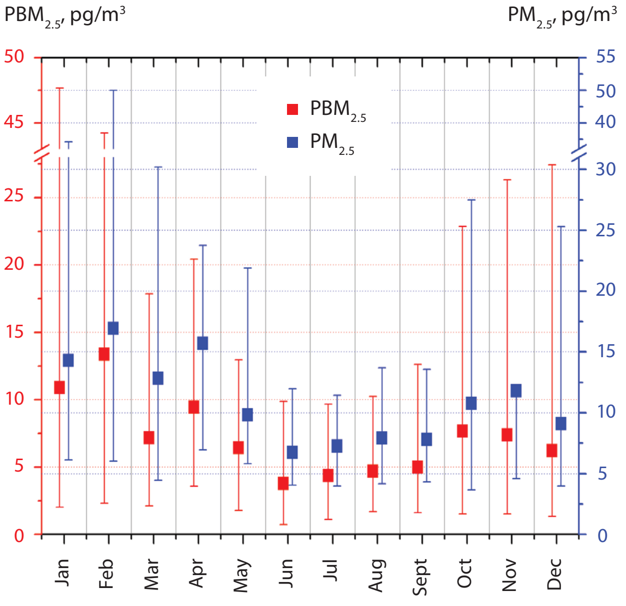


Figure 3.7 Monthly median concentration for particle bound mercury ($PBM_{2.5}$) and particle mass ($PM_{2.5}$) at the Waldhof air monitoring site, Germany (2009–2011). Source: Weigelt et al. (2012).

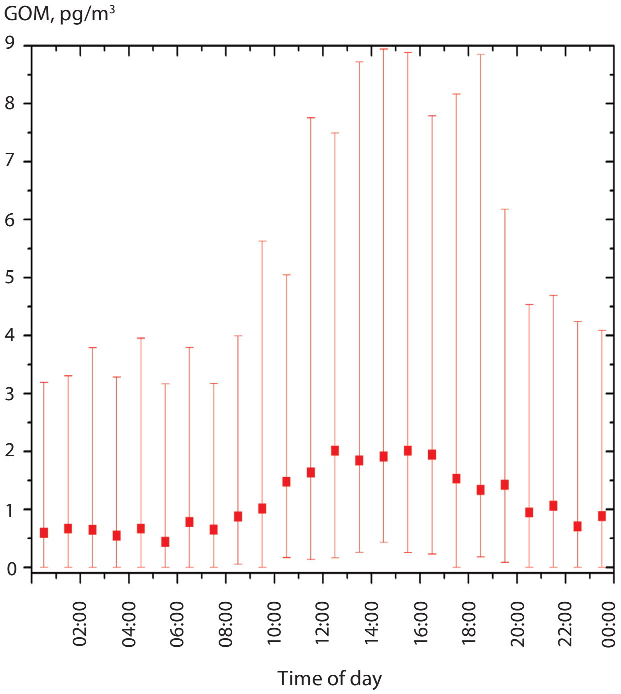


Figure 3.8 Hourly median concentration for GOM at the Waldhof air monitoring site, Germany (2009–2011). Source: Weigelt et al. (2012).

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 (± 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 | $PBM_{2.5}$, pg/m³ | GOM, pg/m³ | Source |
|---|---|---|---|---|---|---|---|---|
| Canada | National (CAMNet) | 1997–1999;<br>1995–2005 | Automated TGM | 1.60 ± 0.15<br>1.58 ± 0.17 | | | | Kellerhals et al., 2003; Temme et al., 2007 |
| | Bay St. François | 2002 | Automated speciated Hg | 1.40 ± 0.17 | 1.38 ± 0.18 | 6.44 ± 3.63 | 3.63 ± 4.07 | Poissant et al., 2004 |
| | St. Anicet, Quebec | 2003 | Automated speciated Hg | | 1.65 ± 0.42 | 26 ± 54 | 3 ± 11 | Poissant et al., 2005 |
| USA | Southern Lake Michigan (LMMBS and AEOLOS) | 1994–1995 | Manual TGM;<br>manual $PBM_{2.5}$;<br>automated TGM | (mean values)<br>2.1–3.6<br>1.7–4.1 | | (mean values)<br>12–70<br>6–133 | | Landis et al., 2002 |
| | SE Michigan (Dexter, Detroit) | 1999–2002 | Automated speciated Hg | | 1.09–4.39<br>1.09–15.74 | (Detroit only)<br>5.70–60.1 | 0.19–38.7<br>0.62–155 | Lynam and Keeler, 2005 |
| | SE Michigan (Detroit) | 2003 | Automated speciated Hg | | 2.2 ± 1.3 | 20.8 ± 30.0 | 17.7 ± 28.9 | Liu et al., 2007 |
| | SE Michigan (Dexter, Detroit) | 2004 | Automated speciated Hg | | 1.59 ± 0.59<br>2.47 ± 1.43 | 6.10 ± 5.51<br>18.1 ± 61.0 | 3.80 ± 6.62<br>15.5 ± 54.9 | Liu et al., 2010 |
| | New York (Potsdam, Stockton, Sterling) | 2001–2002 | Manual TGM;<br>manual GOM | 1.84 ± 1.24<br>1.83 ± 1.32<br>3.02 ± 2.14 | | | 4.2 ± 0.64<br>5.7 ± 9.2<br>6.0 ± 10.8 | Han et al., 2004 |
| | New York (Adirondacks) | 2006–2007 | Automated speciated Hg | | 1.4 ± 0.4 | 3.2 ± 3.7 | 1.8 ± 2.2 | Choi et al., 2008 |
| | 20 AMNet Sites | 2008–2009 | Automated speciated Hg | | (annual mean)<br>1.2–2.1 | (annual mean)<br>2.9–17.1 | (annual mean)<br>1.1–22.6 | Zhang et al, 2012a |

Arctic (Kuujjuarapik, Nunavik, Quebec, Canada) and mid-latitude sites (St. Anicet, Quebec, Kejimkujik, 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 Kuujjuarapik 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, Kejimkujik, and Egbert, respectively (Cole et al., 2012). These trends are in close agreement with that observed since 1996 at Mace Head, Ireland (-1.8 ± 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 $PBM_{2.5}$ 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 ± 0.01 ng/m³/y, or -3.1 ± 1.1 ppqv/y) and at Cape Point, South Africa (-0.034 ± 0.005 ng/m³/y, or -3.8 ± 0.6 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

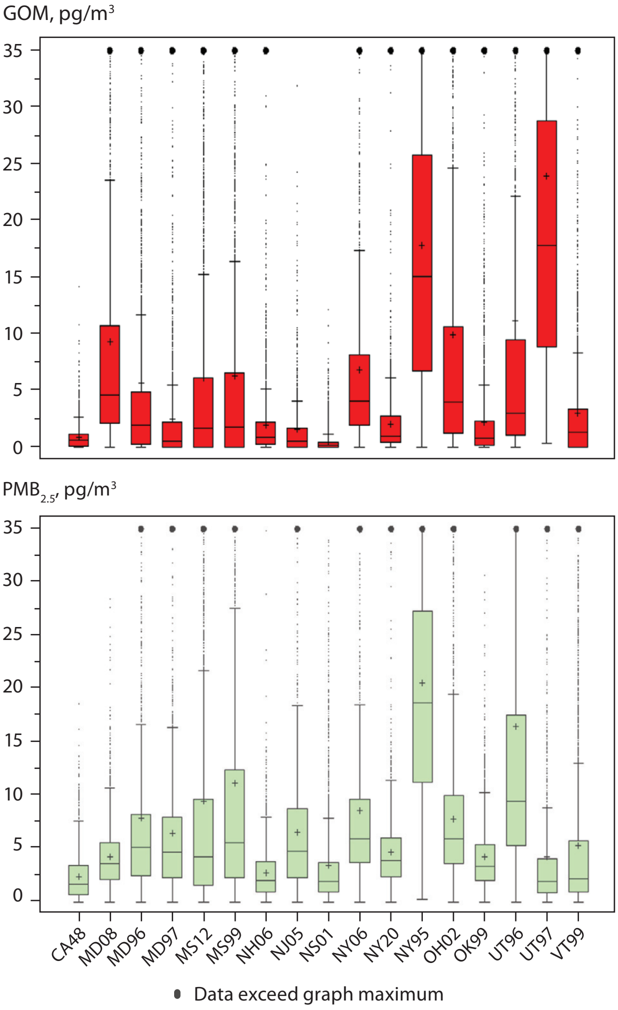


Figure 3.9 Annual GOM and $PBM_{2.5}$ observations for AMNet sites in 2010. The box whisker plots for each field site show the median (horizontal line), 70th percentile (box), 95th percentile (whisker). In general, urban and regionally impacted sites had the highest mercury speciation values, while remote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

GOM and $PBM_{2.5}$ 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 $PBM_{2.5}$ the annual concentrations were more variable among the sites. While the lowest concentrations of GOM and $PBM_{2.5}$ were observed at the same rural sites, the highest concentrations of GOM and $PBM_{2.5}$ 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, $PBM_{2.5}$, GOM) in Guiyang were also conducted in 2009. The mean GEM, $PBM_{2.5}$ 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 ± 0.37 ng/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 $PBM_{2.5}$ 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 $PBM_{2.5}$ 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 $PBM_{2.5}$ 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, $PBM_{2.5}$ 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/m³ | PBM, pg/m³ | GOM, pg/m³ | 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<br>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<br>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<br>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<br>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 $O_3$ 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 $O_3$ 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/m$^3$) 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

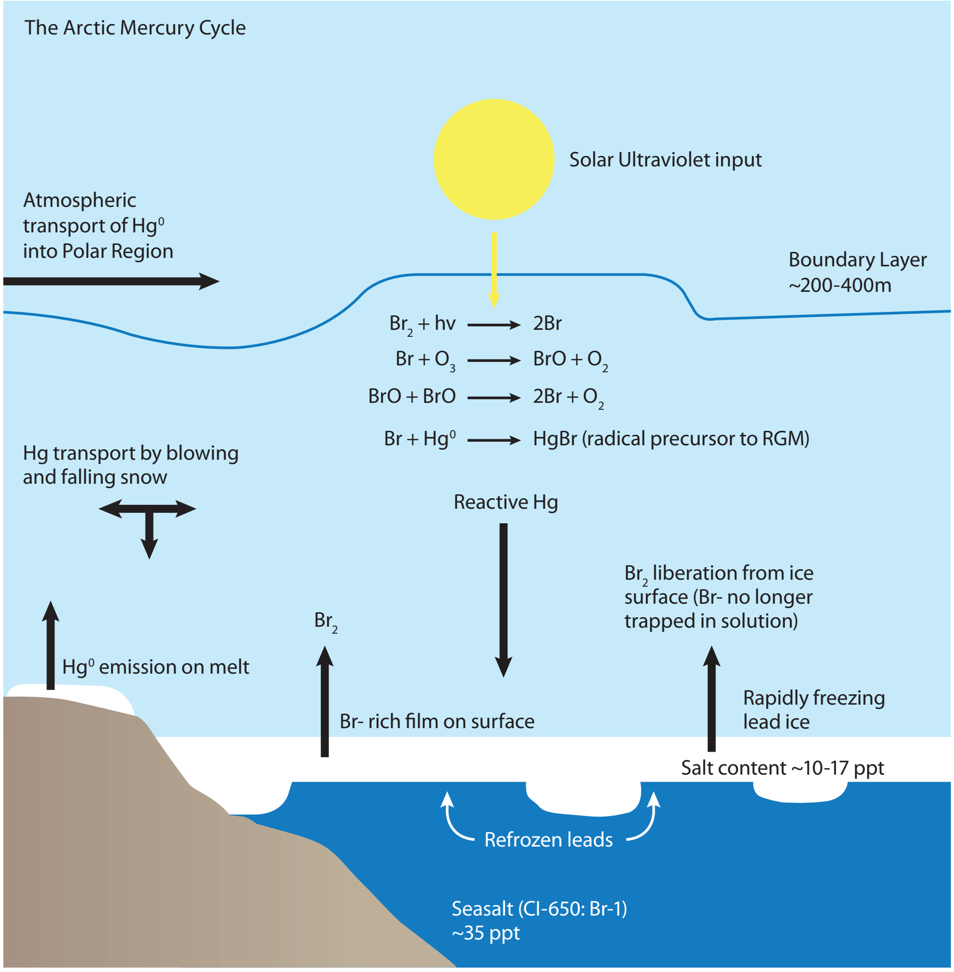


Figure 3.10 Schematic description of atmospheric bromine production and the possible fate of mercury after its chemical reactions with bromine-containing compounds and its deposition. Source: AMAP/UNEP (2008).

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

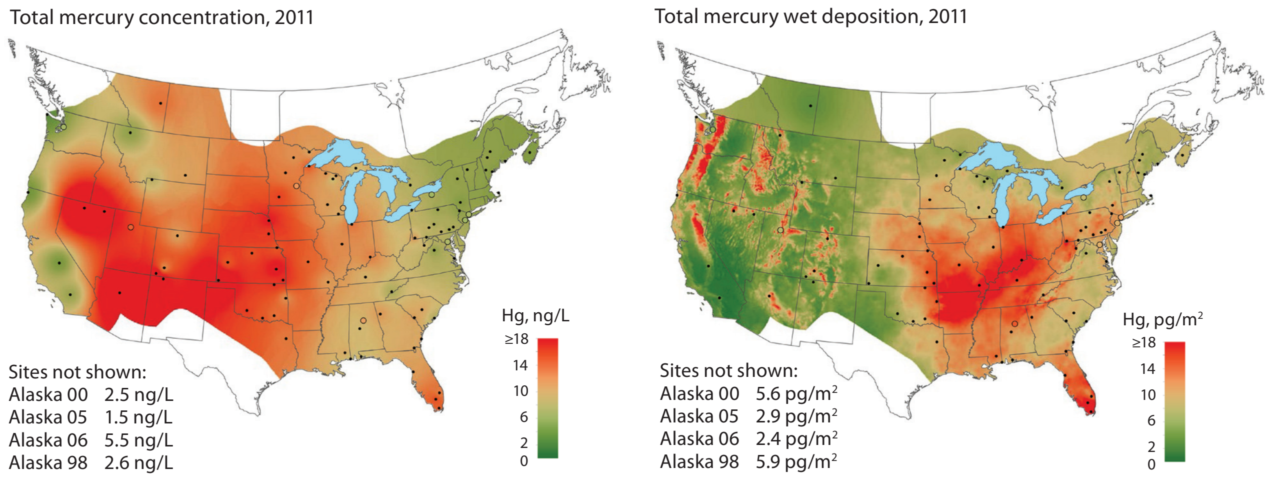


Figure 3.11 Total mercury concentration and wet deposition annual gradient maps for North America from the NADP-MDN programme for 2011. Source: http://nadp.sws.uiuc.edu/mdn/annualmdnmaps.aspx.

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 µg/m²/y and 5.8–26.1 µg/m²/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.; [b]elevation 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; Faïn 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-IIA) 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/m$^3$ (range 0.7–2.6 ng/m$^3$) (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).

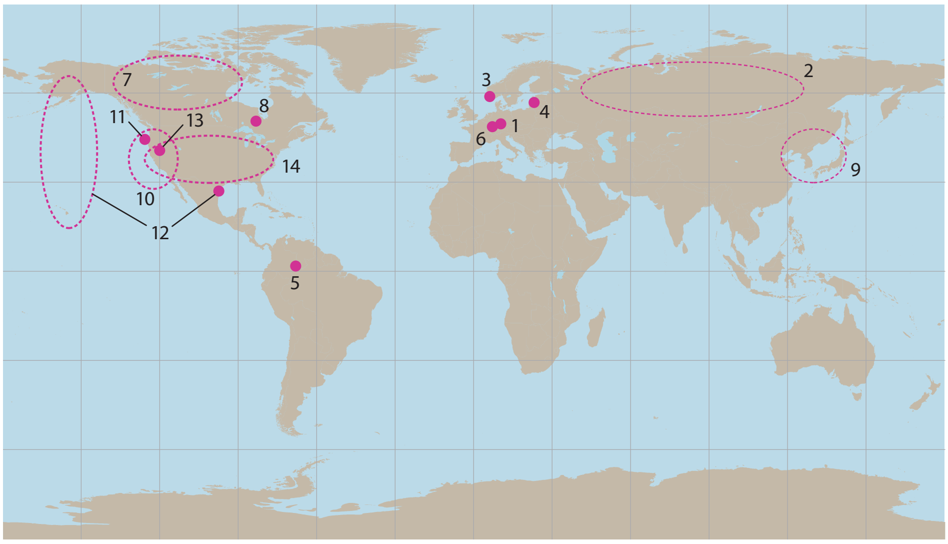
Another interesting addition to the GMOS network has been the French-Italian base, Dome Concordia Station (Dome-C) in Antarctica. Measurements of GEM using the Tekran 2537 Mercury Vapour Analyser began at Dome C (75°06'S, 123°20'E, 3320 m a.s.l.) in December 2011. Dome C is located on the Antarctic plateau, 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
2 Kvietkus et al., 1985, 1995
3 Brosset, 1987
4 Kvietkus et al., 1995
5 Artaxo et al., 2000
6 Ebinghaus and Slemr, 2000
7 Banic et al., 2003
8 Friedli et al., 2003
9 Friedli et al., 2004
10 Radke et al., 2007
11 Swartzendruber et al., 2008
12 Talbot et al., 2008
13 Swartzendruber et al., 2009
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/$m^3$.

Very recently, new instrumentation has been developed to measure oxidised Hg compounds as well (Lyman and Jaffe, 2012). Measurements of total Hg, GOM, and $O_3$ 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.

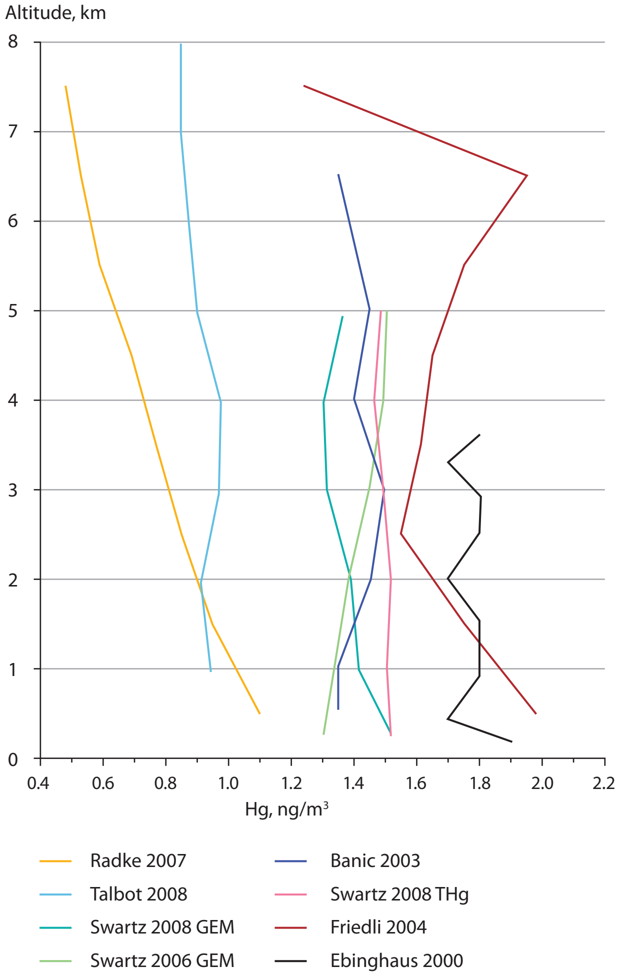


Figure 3.13 Comparison of known vertical gaseous mercury profiles (TGM and GEM). Source: Swartzendruber et al., 2009 (and references therein).

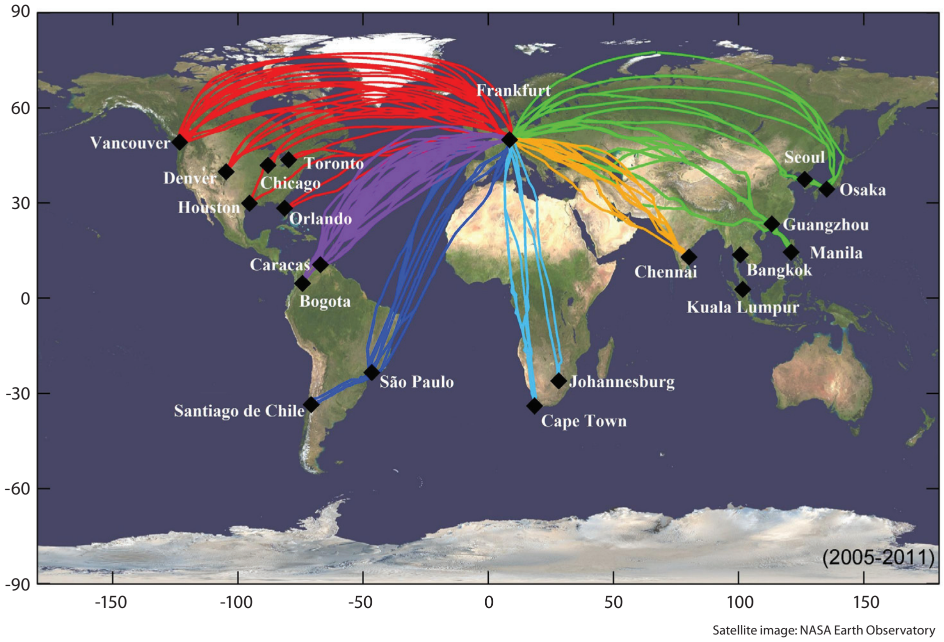
### 3.5.2.2 The European CARIBIC project

CARIBIC (**C**ivil **A**ircraft for the **R**egular **I**nvestigation of the atmosphere **B**ased on an **I**nstrument **C**ontainer) 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, $O_3$, NO, $NO_Y$, $CO_2$, 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 ($CH_4$). 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/m$^3$. 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 $CH_4$) 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., $HgBr_2$, $HgCl_2$) 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 $SF_6$. Correlations of TGM with $SF_6$ suggest a seasonally dependent TGM conversion rate of about 0.43 ng/m$^3$/y resulting in a stratospheric TGM lifetime of about 2 years. This lifetime is longer than the several weeks



Satellite image: NASA Earth Observatory

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 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 PBM$_{2.5}$). Depending on the origin of these Hg species, the deposition flux can be divided into two components:

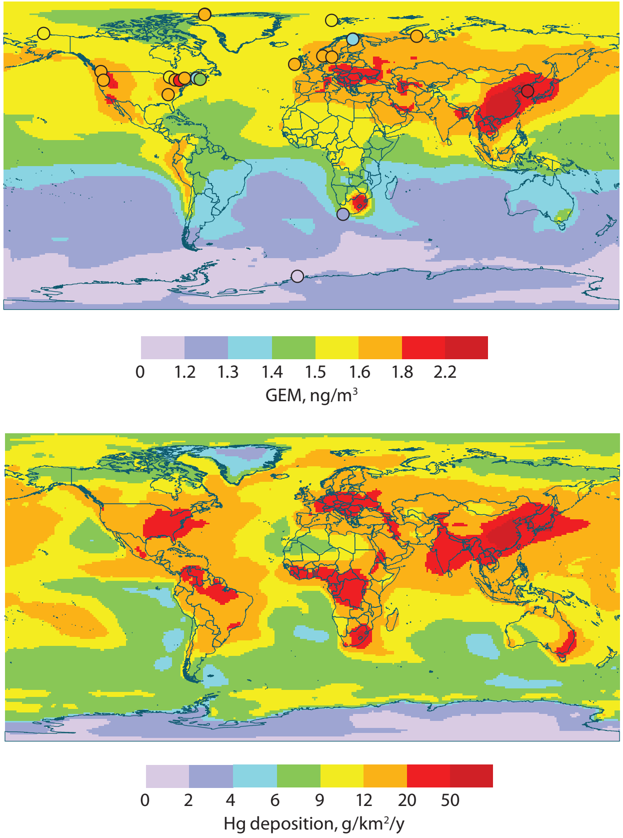


Figure 3.15 Global distribution of ensemble mean annual GEM concentration in ambient air (a) and annual mercury total deposition (b) in 2001. Circles represent long-term observations from the AMAP, EMEP, CAMnet networks and at some other monitoring sites. Source: Travnikov et al. (2010) and references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

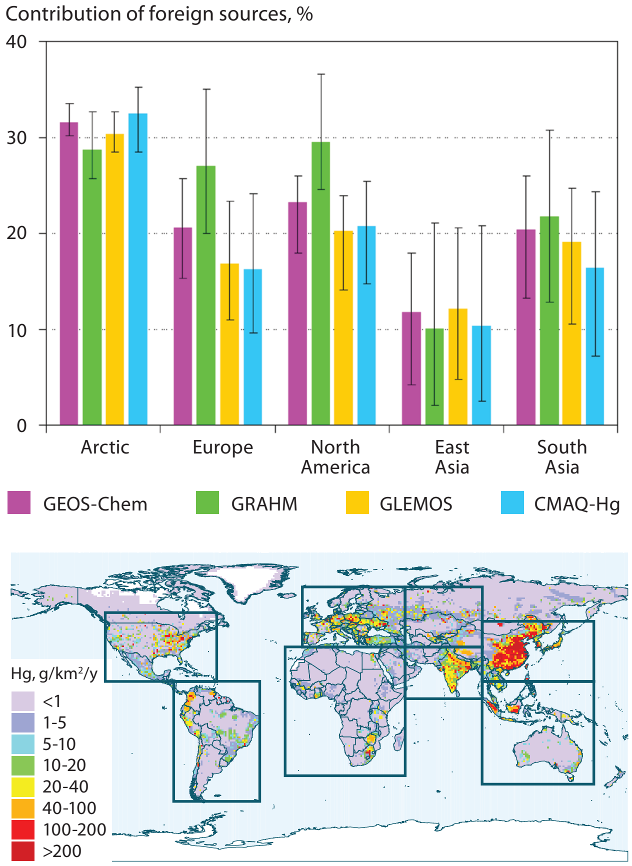


Figure 3.16 (a) Contribution of foreign anthropogenic sources to mercury deposition in different receptor regions in 2005. Bars represent average values and whiskers show the 90%-confidence interval of the parameter variation over a region. (b) Global distribution of anthropogenic mercury emissions in 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).

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 $O_3$, OH, $H_2O_2$, and/or reactive halogens (Br, BrO, $Br_2$, Cl, ClO, $Cl_2$, 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 $O_3$ 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

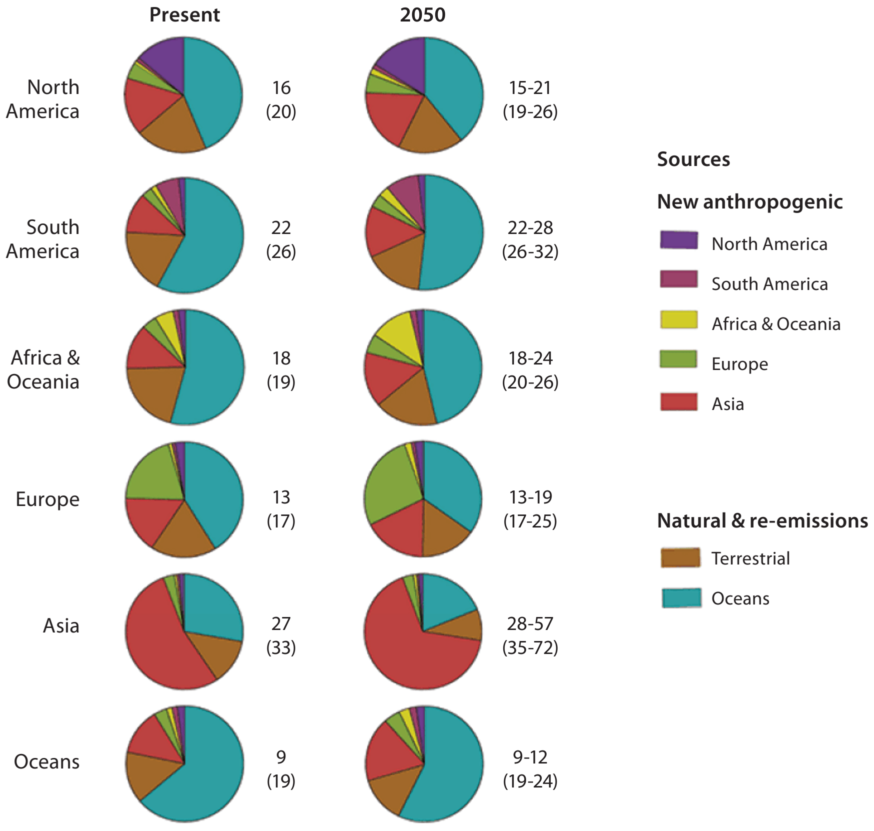


Figure 3.17 Sources of mercury deposited to aggregated world regions for the present-day and for 2050 based on four IPCC emissions scenarios (A1B, A2, B1, B2). Numbers give annual net deposition fluxes to the receptor region (gross deposition fluxes in parentheses) and for 2050 represent the range of 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; Travnikov 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; Hedgecock et al., 2006; Pan et al., 2006; Roustan and Bocquet, 2006; Voudouri and Kallos, 2007; Travnikov 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 Travnikov and Ilyin (2009) for operational simulations of transboundary Hg pollution within Europe. They found systematically elevated TGM concentrations (1.6–2 $ng/m^3$) and wet deposition fluxes (10–20 $\mu g/m^2/y$) 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

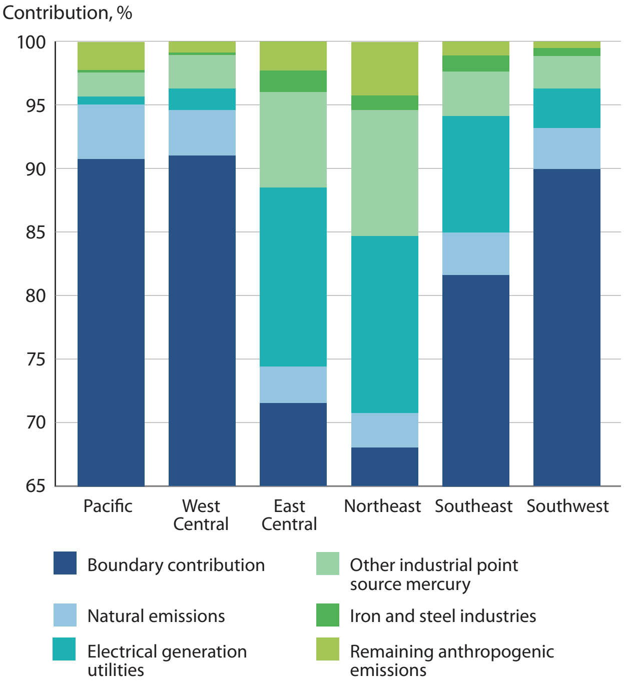


Figure 3.18 Source contribution to annual mercury deposition by the source sectors in six sub-regions of the United States. Source: adapted from Lin et al. (2012).

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–O$_3$ 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$^{-20}$ cm$^3$/molec/s) and O$_3$ (3.0 × 10$^{-20}$ cm$^3$/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 O$_3$ (Case 3), no oxidation by either OH or O$_3$ (Case 4), using a higher kinetic constant for the O$_3$ oxidation pathway (7.5 × 10$^{-19}$ cm$^3$/molec/s) (Case 5), assuming that there is no HgII reduction by aqueous HO$_2$ (Case 6), and finally no reduction by aqueous HO$_2$ 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 O$_3$ 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–O$_3$ reaction causes much greater wet deposition (Case 5). Removing the aqueous reduction of HgII by HO$_2$ 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 HO$_2$ proceeds more rapidly in the model than GEM oxidation by OH. The magnitude of uncertainty in total wet deposition in the modelling

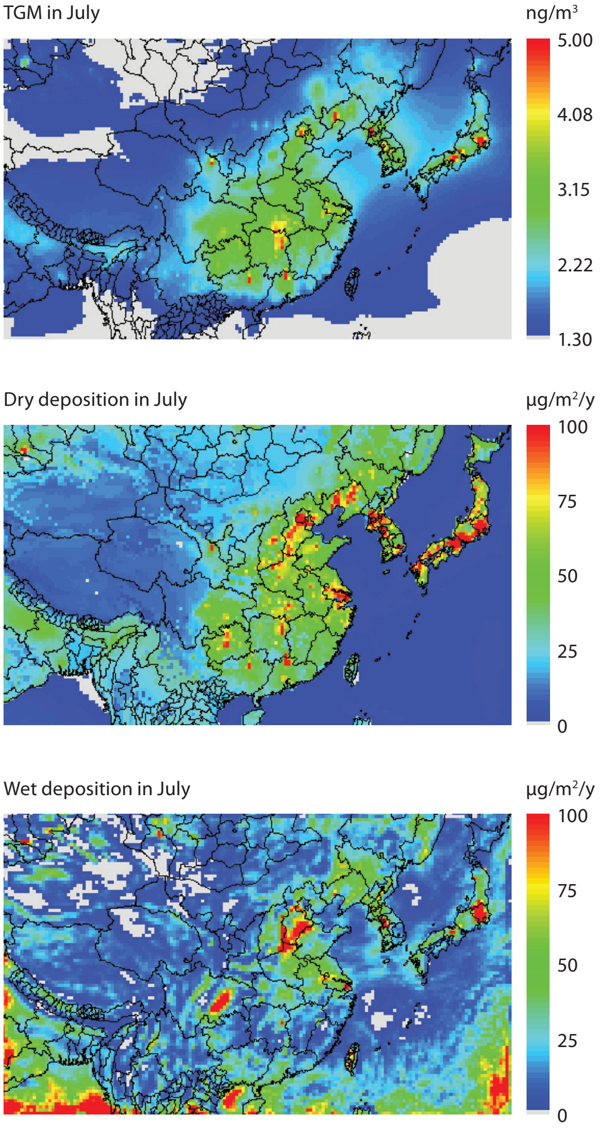


Figure 3.19 Spatial distribution of the monthly average surface air concentrations of total mercury (GEM + GOM+ PBM$_{2.5}$) (a), and monthly cumulative dry deposition (b) and cumulative wet deposition (c) normalised to annual deposition (µg/m$^2$/y). Source: adapted from Lin et al. (2010).

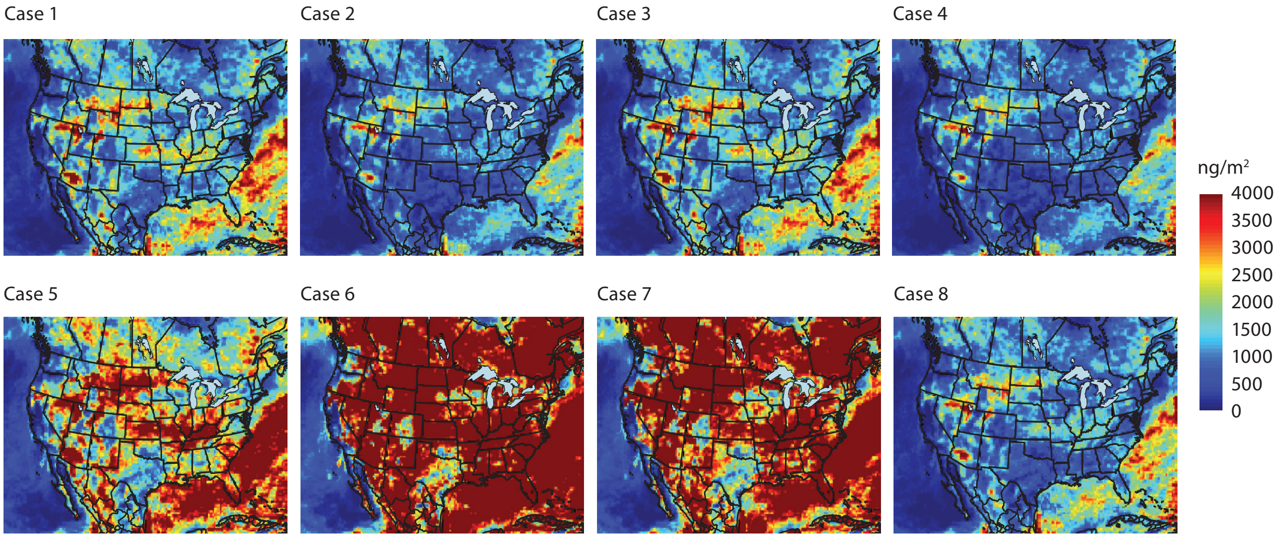


Figure 3.20 Impact of mercury chemistry uncertainty on the simulated monthly mercury wet deposition for the United States in July 2001. The graphic shows eight simulations - see the main text for details. Source: adapted from Travnikov et al. (2010) (cited in: Pirrone and Keating, 2010).

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 $PBM_{2.5}$, has been limited by lack of ambient measurement data. Holloway et al. (2012) evaluated GEM, GOM, and $PBM_{2.5}$ 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, $PBM_{2.5}$) 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 update 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.

# Acknowledgements

Dr. Nicola Pirrone, Chair of the UNEP F&T, would like to express his gratitude to the members of the partnership for their continued support to the activity of the UNEP F&T partnership area over the past seven years.

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).*

Dr. Pirrone also wishes to acknowledge the support received from the Italian Ministry for the Environment Land and Sea, in particular the Minister Mr Corrado Clini. The contribution of the European Commission through the funding of the GMOS project is greatly acknowledged.

# 4. Global Releases of Mercury to Aquatic Environments

**Authors:** David Kocman, Milena Horvat, Simon Wilson

**Contributors:** Peter Outridge, Kevin Telmer

## 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.

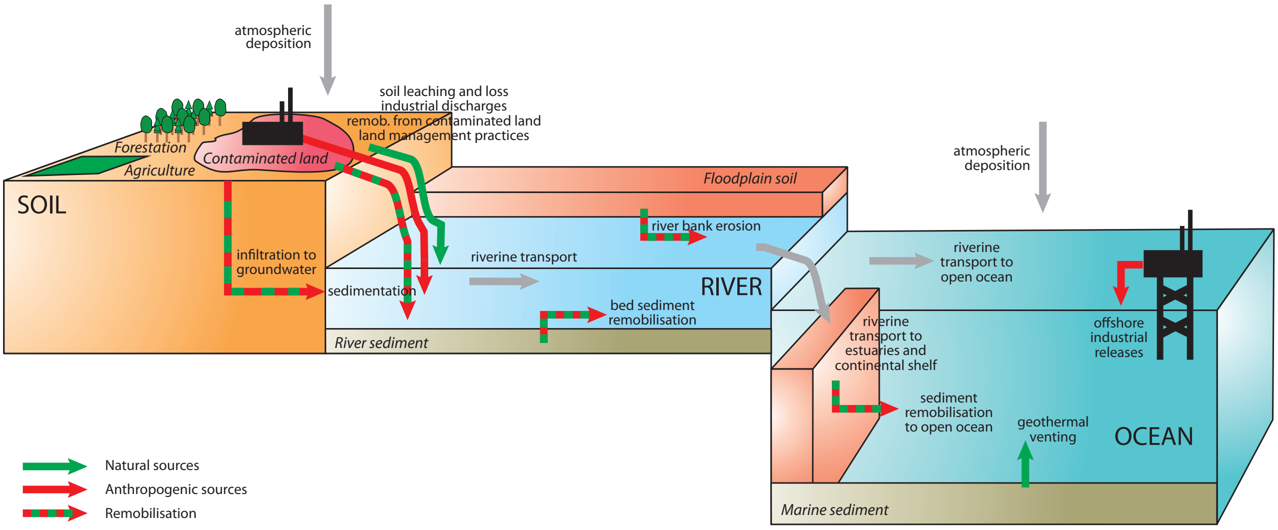


Figure 4.1. Schematic illustration of the major pathways and sources of mercury to aquatic environments.

## 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 1–3 $\mu g/m^2/y$, 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 (~$1.5 \times 10^8$ $km^2$ including endoreic regions) results in 150–450 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±20 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: ~320–960 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 g Hg/$km^2$ (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 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)

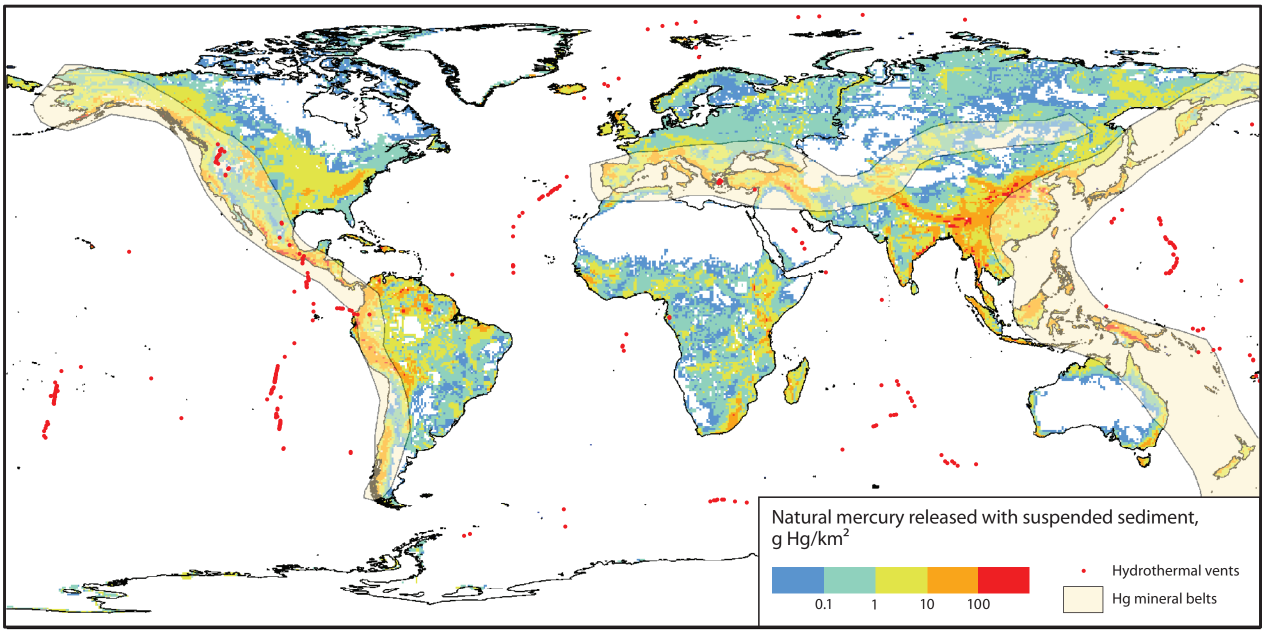


Figure 4.2. Natural mercury fluxes (per 0.5 grid cell) associated with suspended material (based on ISLSCP data (Ludwig et al., 2011a) obtained from: http://dx.doi.org/10.3334/ORNLDAAC/1019) in river systems. The global distribution of mercury mineral belts (modified from Gustin et al., 1999 and Rytuba, 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.

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.*

| | Distribution factors | | |
|---|---|---|---|
| Source category | 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 |

## 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 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<br>(0.001–0.005) | 0.16<br>(0.06–0.81) | 0.03<br>(0.01–0.05) | 0.62<br>(0.37–0.69) |
| Central America and the Caribbean | 0.004<br>(0.002–0.006) | 0.43<br>(0.21–1.83) | 0.04<br>(0.02–0.07) | 1.08<br>(0.55–2.25) |
| CIS & other European countries | 0.043<br>(0.019–0.071) | 2.77<br>(0.99–13.9) | 0.07<br>(0.02–0.15) | 1.94<br>(0.74–4.44) |
| East and Southeast Asia | 0.381<br>(0.172–0.629) | 6.45<br>(2.38–31.8) | 0.69<br>(0.24–1.42) | 9.29<br>(5.21–14.9) |
| EU27 | 0.081<br>(0.039–0.134) | 1.11<br>(0.40–5.58) | 0.05<br>(0.02–0.10) | 1.13<br>(0.46–2.56) |
| Middle Eastern States | 0.007<br>(0.003–0.011) | 0.53<br>(0.19–2.66) | 0.01<br>(0.002–0.01) | 0.14<br>(0.05–0.33) |
| North Africa | 0.007<br>(0.003–0.012) | – | 0.02<br>(0.01–0.05) | 0.11<br>(0.04–0.27) |
| North America | 0.072<br>(0.034–0.119) | 0.24<br>(0.09–1.17) | 0.01<br>(0.003–0.01) | 0.07<br>(0.04–0.58) |
| South America | 0.012<br>(0.005–0.020) | 3.72<br>(1.33–18.6) | 0.01<br>(0.004–0.02) | 0.95<br>(0.36–2.30) |
| South Asia | 0.028<br>(0.013–0.046) | 2.24<br>(0.80–11.2) | 0.03<br>(0.01–0.07) | 2.16<br>(0.81–5.31) |
| Sub–Saharan Africa | 0.001<br>(0.001–0.002) | 1.11<br>(0.40–5.57) | – | 0.50<br>(0.19–1.24) |
| Total | 0.639<br>(0.293–1.055) | 18.8<br>(6.83–96.16) | 0.95<br>(0.35–1.97) | 18.0<br>(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-Al | NFM-Hg | NFM-Au | CAP | Other waste | ASGM[a] |
|---|---|---|---|---|---|
| 0.21<br>(0.08–0.44) | – | 6.31<br>(0.04–16.4) | – | 0.47<br>(0.13–1.60) | 3.50 |
| – | – | 1.95<br>(0.02–4.48) | 0.06<br>(0.02–0.12) | 3.40<br>(0.88–11.2) | 6.45 |
| 0.94<br>(0.37–1.95) | 0.53<br>(0.31–0.81) | 8.04<br>(0.06–20.9) | 1.12<br>(0.39–2.17) | 7.00<br>(1.81–23.9) | 10.3 |
| 1.30<br>(0.52–2.45) | 2.27<br>(1.32–3.44) | 11.5<br>(0.08–29.9) | 0.12<br>(0.04–0.24) | 34.3<br>(8.67–118) | 454 |
| 0.03<br>(0.01–0.06) | – | 0.14<br>(0.001–0.36) | 0.65<br>(0.23–1.26) | 4.48<br>(0.93–16.2) | – |
| 0.05<br>(0.02–0.10) | – | 0.25<br>(0.002–0.66) | 0.22<br>(0.08–0.42) | 4.44<br>(1.12–14.8) | – |
| 0.01<br>(0.003–0.02) | 0.02<br>(0.01–0.02) | 0.06<br>(0.0004–0.16) | 0.13<br>(0.05–0.26) | 2.37<br>(0.62–7.59) | – |
| 0.12<br>(0.04–0.24) | – | 0.82<br>(0.01–2.13) | 0.11<br>(0.04–0.21) | 4.57<br>(1.10–16.5) | – |
| 0.21<br>(0.08–0.43) | – | 7.66<br>(0.06–19.6) | 0.25<br>(0.11–0.42) | 7.53<br>(1.96–25.6) | 313 |
| 0.31<br>(0.12–0.64) | – | 0.08<br>(0.001–0.20) | 0.16<br>(0.06–0.31) | 16.6<br>(3.94–58.8) | 0.37 |
| 0.09<br>(0.06–0.12) | – | 11.9<br>(0.10–28.8) | 0.02<br>(0.01–0.04) | 4.18<br>(1.03–13.9) | 93.7 |
| 3.27<br>(1.31–6.45) | 2.82<br>(1.64–4.28) | 48.7<br>(0.36–124) | 2.84<br>(1.02–5.47) | 89.4<br>(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. at., 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.

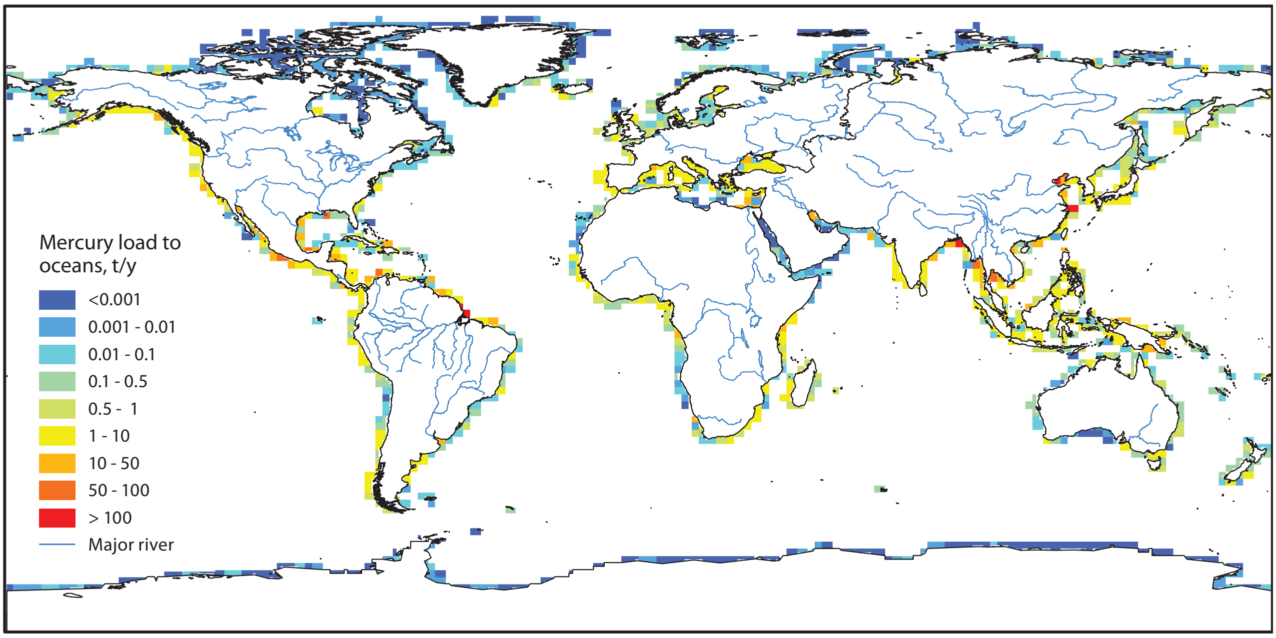


Figure 4.3. Average annual mercury fluxes (per grid cell) to oceans associated with suspended sediments. Source: based on ISLSCP data (Ludwig et. at., 2011b) obtained from: http://dx.doi.org/10.3334/ORNLDAAC/1028

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).

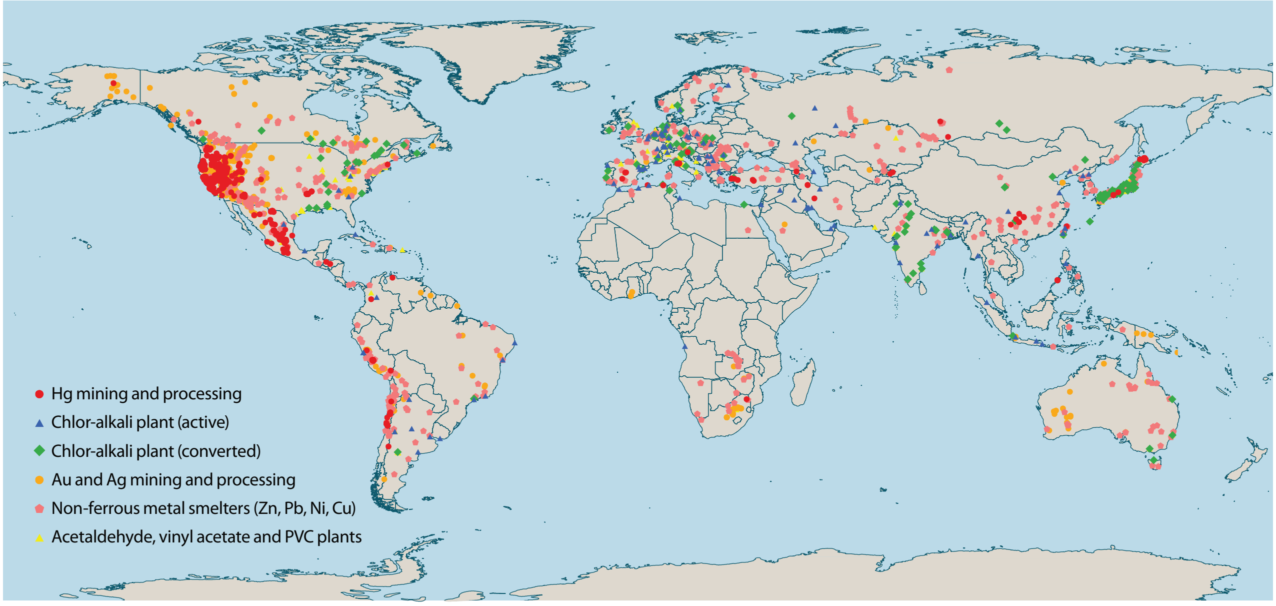


Figure 4.4. Global distribution of mercury-contaminated sites. Source: adapted from Kocman et al. (2013).

*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 km$^2$ 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/m$^2$/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/m$^2$/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 km$^3$ 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

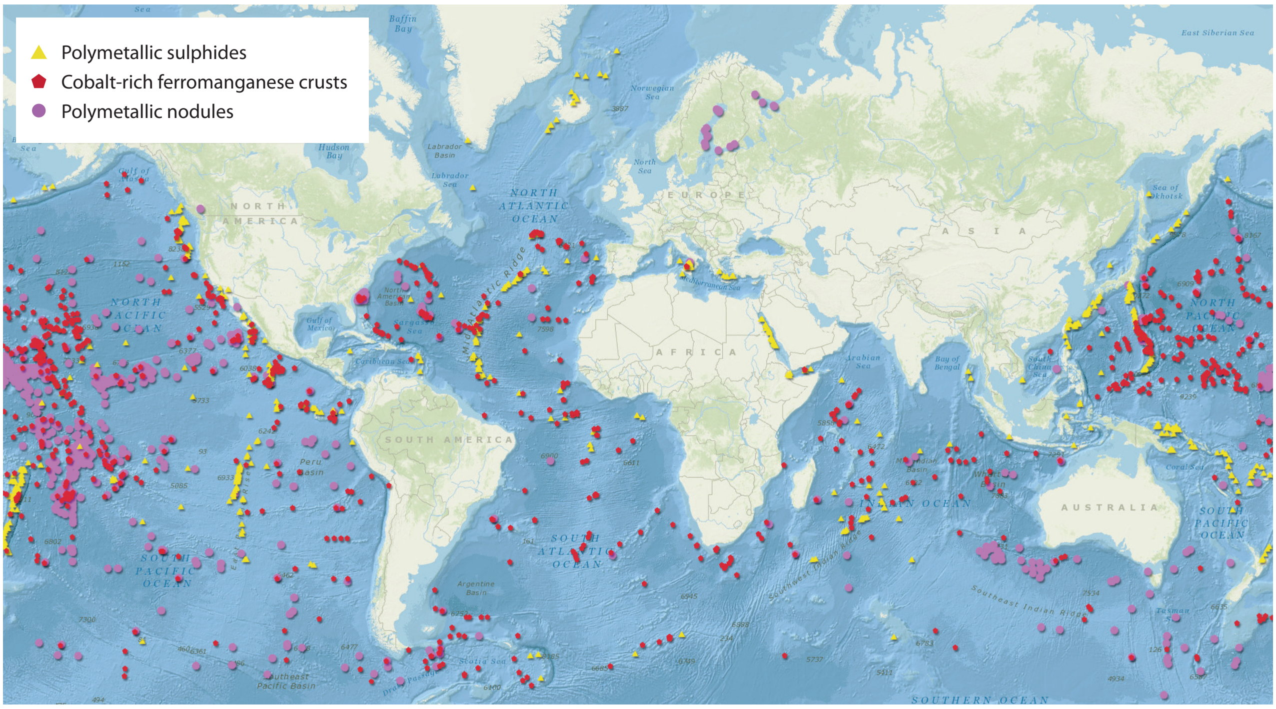


Figure 4.5. Global deep seabed resources. Source: obtained from ISA web GIS application online at: www.mapserver.isa.org.jm/GIS

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 μg/m$^2$/y, export of Hg from contaminated systems can reach hundreds of μg/m$^2$/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 hydrometeorological 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

**Authors:** Peter Outridge, Robert Mason

**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 (Hg0 and HgII), 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 HgII 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; Hg0) 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

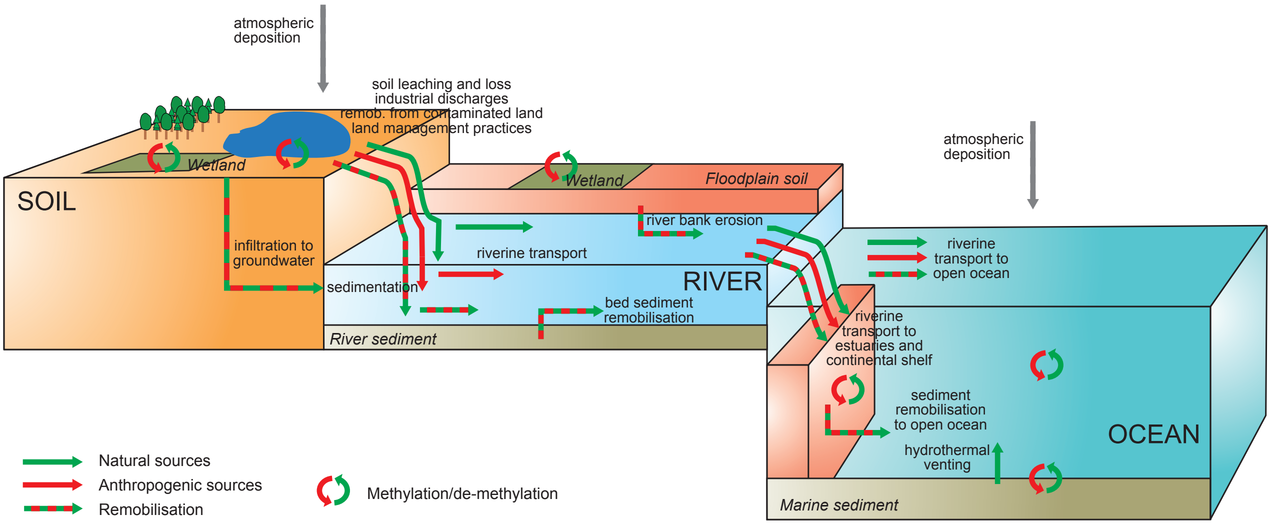


Figure 5.1. Transport pathways of mercury, and general sites of methylation and demethylation, in aquatic systems.

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; Lehnherr 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

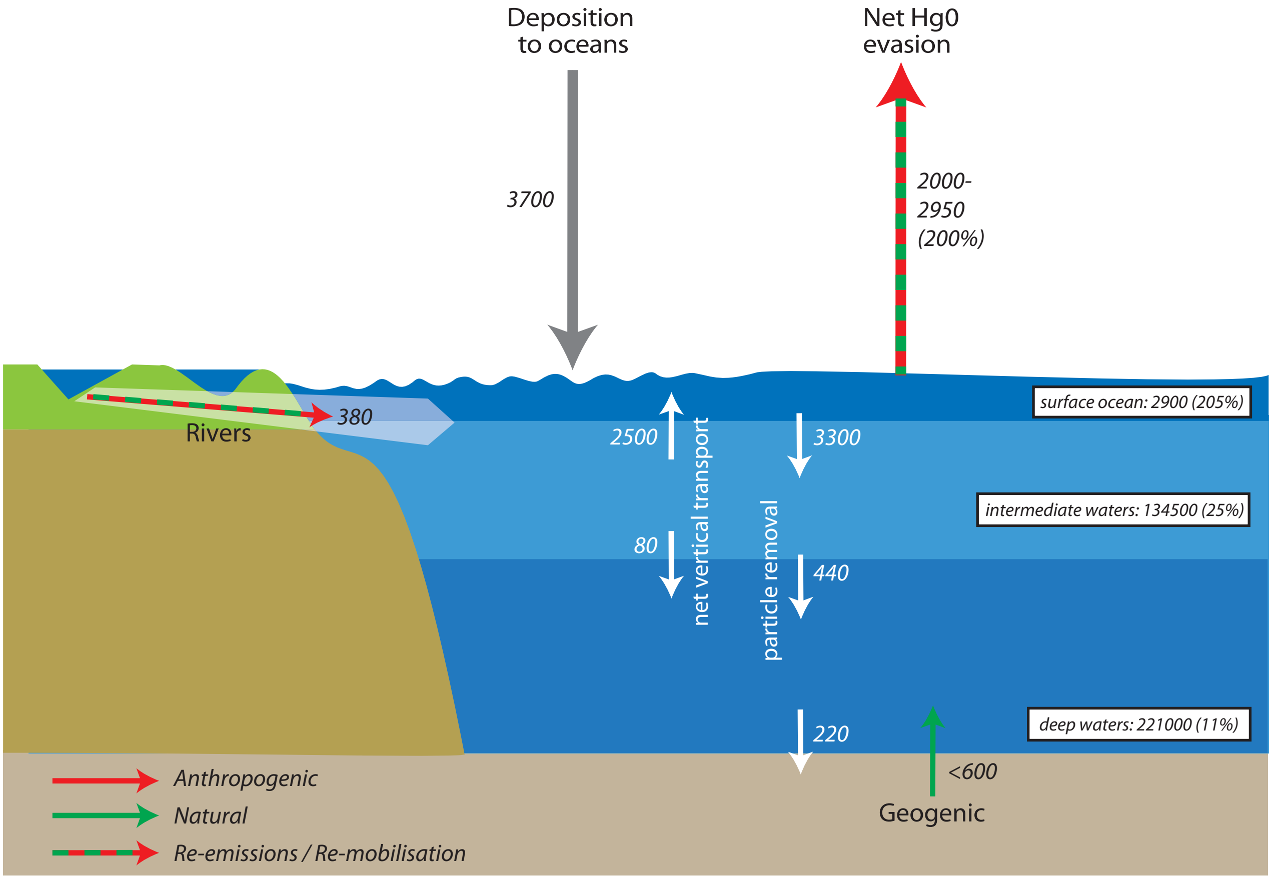


Figure 5.2. A recent estimate of the inventories and fluxes of mercury into and within various layers of the Earth's oceans. Source: adapted from Mason et al. (2012); original Mmol units converted to tonnes by a factor of 200.6. Inventories are in tonnes, and fluxes in tonnes per year. The model is based 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 ΣMeHg, 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; Heimburger et al., 2010; Cossa et al., 2011; Lehnherr 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 ΣMeHg 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 ΣMeHg 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

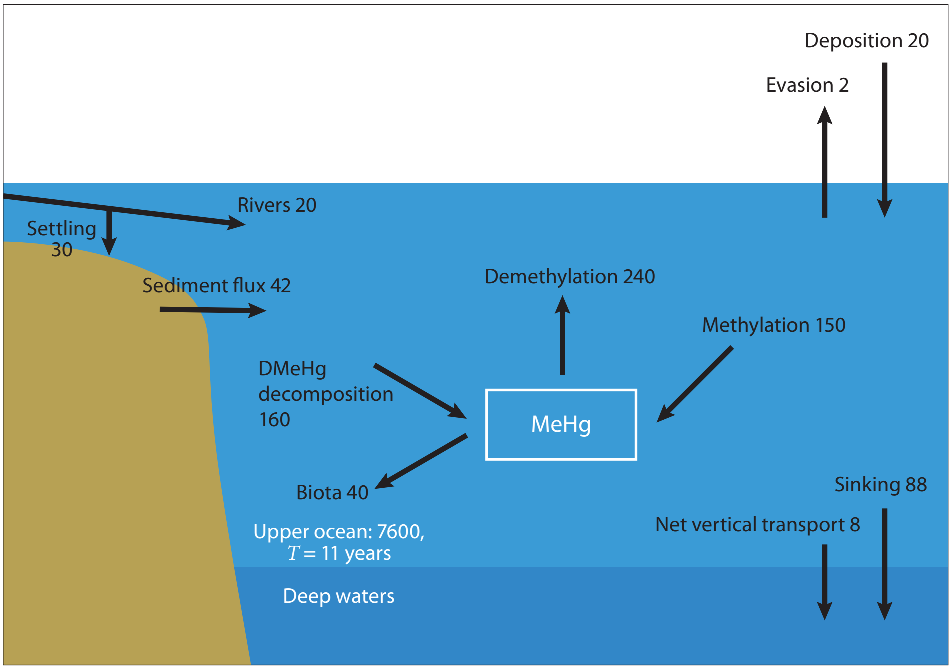


Figure 5.3. Budget for the sources and sinks of monomethyl mercury (MeHg) in the upper ocean (defined as waters above the permanent thermocline, typically <1000 m depth). Source: adapted from Mason et al. (2012). DMeHg – dimethyl mercury. Original Mmol units converted to tonnes by a factor of 200.6. 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, 006b).

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; Heimburger 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; Heimburger 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. Lehnherr 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 (Lehnherr 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 Lehnherr 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; Heimburger 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; Lehnherr 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., Lehnherr 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 μg/m$^2$/y (Grigal, 2002; and references therein). Similar inputs (0.87–4.36 μg/m$^2$/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 μg/m$^2$/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 compared to the northern hemisphere (see Chapters 2 and 3 of this report).

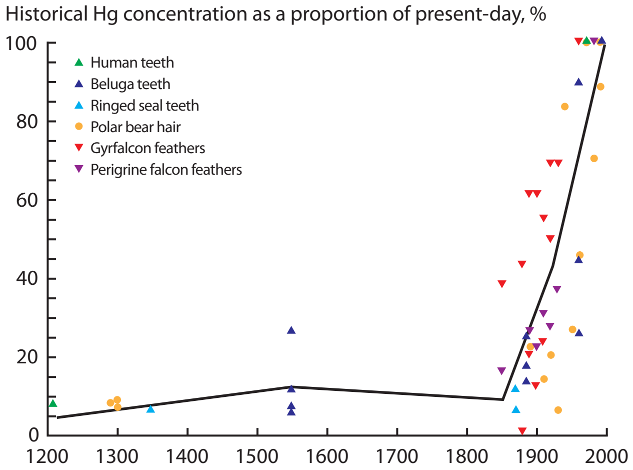


Figure 5.4. Historical trends in mercury concentrations in the hard tissues of Arctic animals and humans, expressed as a percentage of modern maximum annual average concentrations. Source: adapted from AMAP (2011) and Dietz et al. (2009). Most points plotted represent mean values of multiple samples; 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).

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.

# Annex Contents

# 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 allows 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 artisanals'; 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 ±100% (25 countries); class 2 = some indication of quantity of Hg used, estimated average error ±75% (20 countries); class 3 = quantitative data but not significantly updated within past five years, error ±50% (17 countries); class 4 = recent quantitative data; error ±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 ±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 ±100% (25 countries); class 2 = some indication of quantity of Hg used, estimated average error ±75% (20 countries); class 3 = quantitative data but not significantly updated within past five years, error ±50% (17 countries); class 4 = recent quantitative data; error ±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

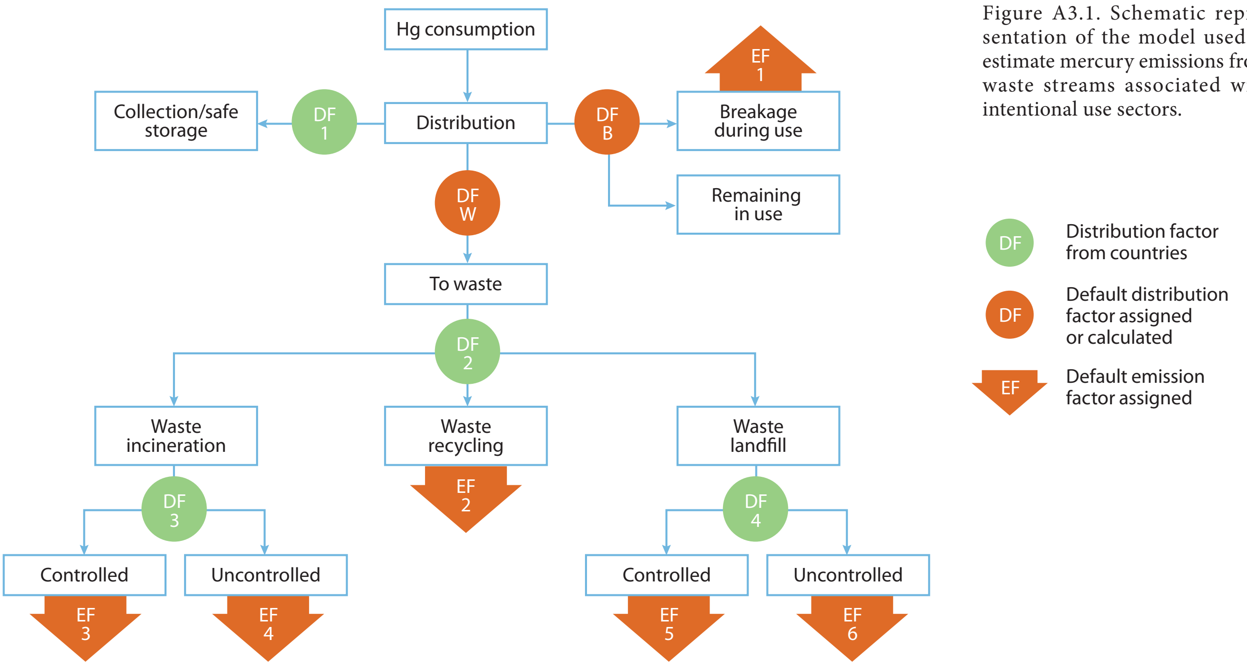


Figure A3.1. Schematic representation of the model used to estimate mercury emissions from waste streams associated with intentional use sectors.

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.

| | Waste distribution pathways | | | | |
|---|---|---|---|---|---|
| Profile | 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.

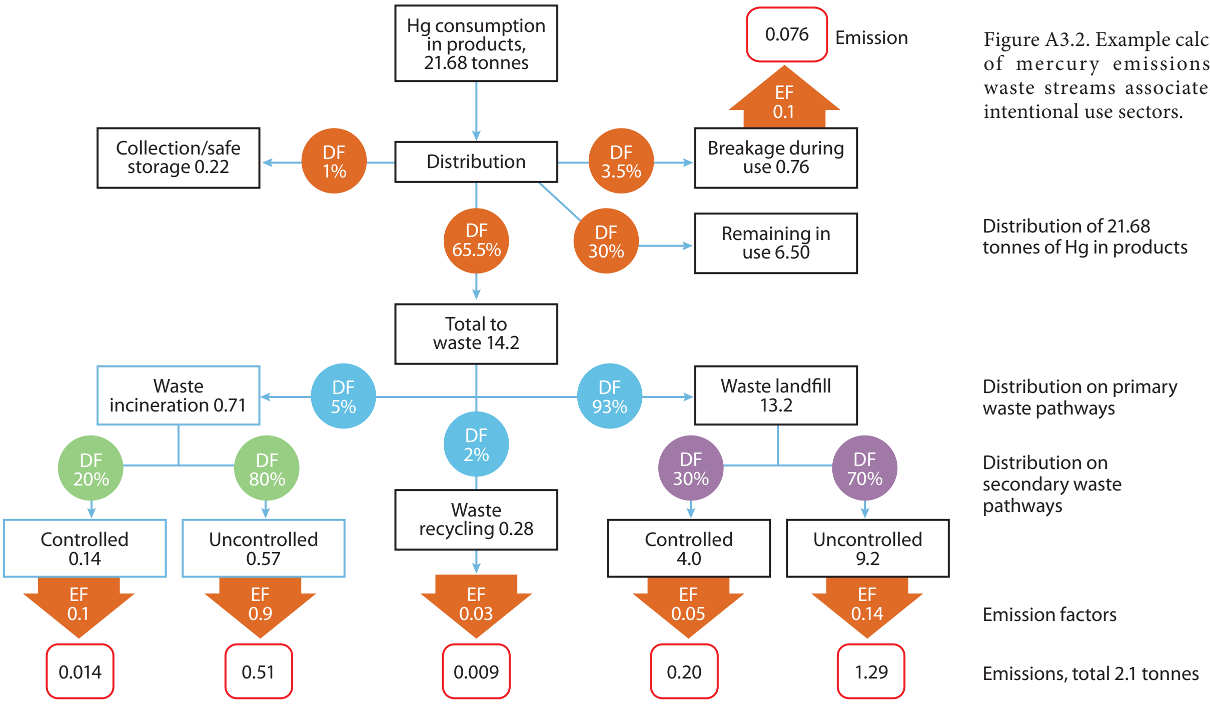


Figure A3.2. Example calculation of mercury emissions from waste streams associated with intentional use sectors.

# 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) |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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) |

| Country Code | Country Name | Sector Code[1] | Activity Code[1] | Activity Amount | Units | Estimate Year | Reference |
|---|---|---|---|---|---|---|---|
| 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<br>All coals – power plants | | 0.2 | | | AMAP/UNEP, 2008 | |
| 2005 inventory<br>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 | | | | | | | | | National comments |
| Particulate matter (FF) | | 50 | | 20 | | | | | |
| 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<br>All coals – power plants | | 0.2 | | | AMAP/UNEP, 2008 | |
| 2005 inventory<br>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 | | g/t | UNEP, 2011b | Twice the UNEP Toolkit default minimum value, see discussion. |
| heavy fuel oil - PP | | 0.02 | | | | |
| light fuel oil - PP | | 0.002 | | | | |
| crude oil - IND | | 0.01 | | | | |
| heavy fuel oil - IND | | 0.02 | | | | |
| 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 m$^3$ (NPL, 2012); generic value 43 MJ per m$^3$ (Engineering Toolbox, 2012)); a value of 40 MJ per m$^3$ has been assumed for purposes of developing a UEF in this work. The UNEP Toolkit emission factors (0.2 and 100 $\mu$g/m$^3$, 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 Nm$^3$/TJ for converting between natural gas volume and calorific value; the correct factor based on the current work would be 25 000 Nm$^3$/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 $\mu$g/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 $\mu$g/m$^3$ |
| | | 0.2 | | $\mu$g/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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Country group | | | | | |
| | low | Intermediate | high | 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 volatised 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 | g/t (primary) pig-iron production | | 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 | | 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Country group | | | | | |
| | low | Intermediate | high | 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 | g/t Pb produced (primary production) | UNEP, 2010a, 2011b; BREF, 2009; country-specific data | 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 | | | | 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 | g/t Zn produced (primary production) | 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 | | 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 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 | | | | 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/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: 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Country group | | | | | |
| | low | intermediate | high | 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 | | 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 | | UNEP, 2011b; BREF, 2009 | National data: 0.2 g Hg/t bauxite |
| 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 | | | |
| ESP | 67 | 9 | UNEP 2010a/P29 study data |
| 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 | | | |
| Particulate matter | 25 | 26 | UNEP 2010a/P29 study data |
| 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, 20011b; 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 | | g/t crude oil refined | | Weighted average of national estimates and their proportional contribution to global supply. |
| Argentina | | 0.004 | | | Wilhelm et al., 2007; Inoue, pers. comm., UNEP, 2011b; IKIMP, 2012 | 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 | | | | 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 | | | | Weighted average based on national estimates and their proportional contribution to global supply for countries within region. |
| Europe | | 0.0033 | | | | |
| Middle East | | 0.0004 | | | | |
| 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Country group | | | | | |
| | low | intermediate | high | 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 × 250 000 × 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.

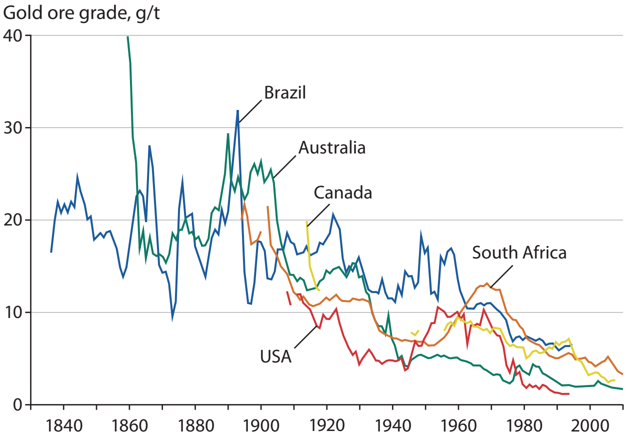


Figure A6.1. Changes in gold ore grade over time in different countries. Source: after Giurco et al., 2010.

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 ($Cl_2$) 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 $Cl_2$ 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):<br>Intermediate: 57.88 g/t $Cl_2$ produced (df 0.1); 15% of production<br>High: 215.97 g/t $Cl_2$ produced (df 0.1); 3.3 % of production;<br>Low: 15.34 g/t $Cl_2$ produced (df 0.245); 82% of production |
| Brazil | | 10 | | | | |
| India | | 10 | | g/t $Cl_2$ capacity | 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 | | | 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) | |
| | Oil | 22.0 (10.4 – 36.3) | 46.6 |
| | 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) | 154.2 [b] |
| | Oil | 88.6 (42.1 – 146.2) | |
| | 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) | 540 [d] |
| | Lead | 12.4 (6.8 – 19.5) | |
| | 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 | | 0 |
| | Lead | | |
| | Zinc | | |
| | Gold (large scale) | | |
| | 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) | |
| | Oil | 116.2 (55.2 – 191.7) | 67 |
| | 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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 |

| Country Code | Country Name | Region | Sector Code[1] | Activity Code[1] | Estimate (min) | Emisssion Estimate, kg | Estimate (max) |
|---|---|---|---|---|---|---|---|
| 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 |

| Country Code | Country Name | Region | Sector Code[1] | Activity Code[1] | Estimate (min) | Emisssion Estimate, kg | Estimate (max) |
|---|---|---|---|---|---|---|---|
| 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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 |

| Country Code | Country Name | Region | Sector Code[1] | Activity Code[1] | Estimate (min) | Emisssion Estimate, kg | Estimate (max) |
|---|---|---|---|---|---|---|---|
| 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) | Emisssion 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 | Monserrat | Central America and the Caribbean | CREM | CREM | 0.002 | 0.007 | 0.023 |
| MSR | Monserrat | Central America and the Caribbean | WASOTH | WASOTH | 0.016 | 0.060 | 0.199 |
| MSR | Monserrat | 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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) | Emisssion 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.

# References

## Web resources

CEMENTA A/B, Sweden. (www.heidelbergcement.com/se/sv/cementa/)

COWI A/S, Denmark. (www.cowi.dk).

Environmental Performance Index, 2010 (http://epi.yale.edu).

Global copper industry outlook (www.trencome.com/copperindustry.htm)

Global Energy Observatorium (www.globalenergyobservatory.org).

Hgtech: Hg in coal, PC, tires, crude oil (www.hgtech.com/Data/Data.html)

IndexMundi (www.indexmundi.com/minerals).

International Zinc Association (www.zinc.org/basics/zinc_production).

Lead fact sheet (www.australianminesatlas.gov.au/education/fact_sheets/lead.html).

Mercury emissions reduction from Portland Cement Kilns using Wet Scrubbers. Paper-2010-A-1419.

North Korean Economy Watch (www.nkeconwatch.com).

OUTOTEC. www.outotec.com/Default.aspx?epslanguage=EN

Power Industry. News, views and contacts from the global Power industry (www.power-technology.com/projects/electricaguacoldapow).

Wikipedia (emission point sources: China, South Africa)

## Personal communications

Baruya, 2012. P. Baruya, IEA Clean Coal Centre.

Devia, 2012. L. Devia, Regional Centre of the Basel Convention - South America Argentina.

Hagström, 2012. P. Hagström, Swedish Environmental Protection Agency.

Hylander, 2012. L.D. Hylander, Uppsala University, Sweden.

Inoue, 2012. Y. Inoue, Petroleum Association of Japan.

Kolker, 2012. A. Kolker, U.S. Geological Survey.

Leaner, 2012. J. Leaner, Environmental Affairs and Development Planning, Cape Town, South Africa.

Maag, 2012. J. Maag, Department of Pollution Prevention, Risk Management and Sustainability, COWI A/S.

Maioli, 2012. O. Maioli, Ministry of Environment, Brasilia, Brazil.

Maxson, 2012. P. Maxson, European Commission, Belgium.

Nelson, 2012. P. Nelson, Macquarie University, New South Wales, Australia.

Pudasainee, 2012. D. Pudasainee, Karlshruhe Institue of Technology, Germany.

Seo, 2012. Y.-C. Seo, Yonsei University, Wonju, Republic of Korea.

Solórzano, 2012. G. Solórzano, Ministry of Environment, Mexico.

Strum, 2012. M. Strum, U.S. Environmental Protection Agency.

Suzuki, 2012. N. Suzuki, National Institute for Environmental Studies, Japan.

Wang, 2012. S. Wang, Tsinghua University, People's Republic of China.

## General references

Ahn, M.-C., S.-M. Yi, T.M. Holsen and Y.-J. Han, 2011. Mercury wet deposition in rural Korea: concentrations and fluxes. Journal of Environmental Monitoring, 13:2748-2754.

AMAP, 2009. AMAP Assessment 2009: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo. 254 pp.

AMAP, 2010. Updating Historical Global Inventories of Anthropogenic Mercury Emissions to Air. By: Wilson, S., J. Munthe, K. Sundseth, K. Kindbom, P. Maxson, J. Pacyna and F. Steenhuisen. AMAP Technical Report No. 3. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 12 pp.

AMAP, 2011. AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo. 193 pp.

AMAP/UNEP, 2008. Technical Background Report to the Global Atmospheric Mercury Assessment. Arctic Monitoring and Assessment Programme / UNEP Chemicals Branch. 159 pp. Online at: www.chem.unep.ch/mercury/Atmospheric_Emissions/Technical_background_report.pdf

Amiotte-Suchet, P. and J.L. Probst, 1995. A global model for present day atmospheric/soil $CO_2$ consumption by chemical erosion of continental rocks (GEM-CO2). Tellus, 47B:273-280.

Amos, H.M., D.J. Jacob, C.D. Holmes, J.A. Fisher, Q. Wang, R.M. Yantosca, E.S. Corbitt, E. Galarneau, A.P. Rutter, M.S. Gustin, A. Steffen, J.J. Schauer, J.A. Graydon, V.L.S. Louis, R.W. Talbot, E.S. Edgerton, Y. Zhang and E.M. Sunderland, 2012. Gas-particle partitioning of atmospheric Hg(II) and its effect on global mercury deposition. Atmospheric Chemistry and Physics, 12:591-603.

Andersson, M.E., K. Gårdfeldt, I. Wängberg, F. Sprovieri, N. Pirrone and O. Lindqvist, 2007. Seasonal and daily variation of mercury evasion at coastal and off shore sites from the Mediterranean Sea. Marine Chemistry, 104:214-226.

Andersson, M.E., J. Sommar, K. Gardfeldt and O. Lindqvist, 2008. Enhanced concentrations of dissolved gaseous mercury in the surface waters of the Arctic Ocean. Marine Chemistry, 110:190-194.

Andersson, M., J. Sommar, K. Gårdfeldt and S. Jutterström, 2011. Air–sea exchange of volatile mercury in the North Atlantic Ocean. Marine Chemistry, 125:1-7.

Appelquist, H., I. Drabæk and S. Asbirk, 1985. Variation in mercury content of guillemot feathers over 150 years. Marine Pollution Bulletin, 16:244-248.

Ariya, P.A., K. Peterson, G. Snider and M. Amyot, 2009. Mercury chemical transformations in the gas, aqueous and heterogeneous phases: state-of-the-art science and uncertainties. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 459-501. Springer.

Baeyens, W., M. Leermakers, T. Papina, A. Saprykin, N. Brion, J. Noyen, M. De Gieter and L. Goeyens, 2003. Bioconcentration and biomagnification of mercury and methylmercury in North Sea and Scheldt Estuary fish. Archives of Environmental Contamination and Toxicology, 45:498-508.

Baker, K.R. and J.O. Bash, 2012. Regional scale photochemical model evaluation of total mercury wet deposition and speciated ambient mercury. Atmospheric Environment, 49:151-162.

Baker, A.K., F. Slemr and C.A.M. Brenninkmeijer, 2010. Analysis of non-methane hydrocarbons in air samples collected aboard the CARIBIC passenger aircraft. Atmospheric Measurement Techniques, 3:311-321.

Balcom, P.H., C.R. Hammerschmidt, W.F. Fitzgerald, C.H. Lamborg and J.S. O'Connor, 2008. Seasonal distributions and cycling of mercury and methylmercury in the waters of New York/New Jersey Harbor Estuary. Marine Chemistry, 109:1-17.

Balcom, P.H., W.F. Fitzgerald and R.P. Mason, 2010. Synthesis and assessment of heavy metal contamination in the Hudson River and New York/New Jersey estuary with emphasis on Hg and Cd. Final Report, Hudson River Foundation. Online at: www.hudsonriver.org/ls/reports/Fitzgerald_003_05A_final_report.pdf

Banic, C., S. Beauchamp, R. Tordon, W. Schroeder, A. Steffen, K. Anlauf and H. Wong, 2003. Vertical distribution of gaseous elemental mercury in Canada. Journal of Geophysical Research (Atmospheres), 108:4264.

Bash, J.O., 2010. Description and initial simulation of a dynamic bidirectional air-surface exchange model for mercury in Community Multiscale Air Quality (CMAQ) model. Journal of Geophysical Research, 115:D06305.

Bearhop, S., G.D. Ruxton and R.W. Furness, 2000. Dynamics of mercury in blood and feathers of great skuas. Environmental Toxicology and Chemistry, 19:1638-1643.

Béliveau, A., M. Lucotte, R. Davidson, L.O. Canto Lopes and S. Paquet, 2009. Early Hg mobility in cultivated tropical soils one year after slash-and-burn of the primary forest, in the Brazilian Amazon. Science of the Total Environment, 407:4480-4489.

Benoit, J.M., D.H. Shull, R.M. Harvey and S.A. Beal, 2009. Effect of bioirrigation on sediment–water exchange of methylmercury in Boston Harbor, Massachusetts. Environmental Science and Technology, 43:3669-3674.

Berg, T., S. Sekkesæter, E. Steinnes, A.-K. Valdal and G. Wibetoe, 2003. Springtime depletion of mercury in the European Arctic as observed at Svalbard. Science of the Total Environment, 304:43-51.

Bergquist, B.A. and J.D. Blum, 2007. Mass-dependent and -independent fractionation of Hg isotopes by photoreduction in aquatic systems. Science, 318:417-420.

Bergquist, B.A. and J.D. Blum, 2009. The odds and evens of mercury isotopes: applications of mass-dependent and mass-independent isotope fractionation. Elements, 5:353-357.

Berlin, M., 1986. Mercury. In: Friberg, L., G.F. Nordberg and V.B. Vouk (Eds.). Handbook on the Toxicology of Metals. Elsevier Science Publishers. pp. 187-445.

Berzas Nevado, J.J., R.C. Rodríguez Martín-Doimeadios, F.J. Guzmán Bernardo, M. Jiménez Moreno, A.M. Herculano, J.L.M. do Nascimento and M.E. Crespo-López, 2010. Mercury in the Tapajós River basin, Brazilian Amazon: a review. Environment International, 36:593-608.

Biester, H., G. Muller and H.F. Scholer, 2002. Binding and mobility of mercury in soils contaminated by emissions from chlor-alkali plants. Science of the Total Environment, 284:191-203.

Bilans, 2010. Bilans Gospodarki Surowcami Mineralnymi Polski i Świata 2008, PAN, Kraków 2010.

BIO Intelligence Service, 2012. Study on the potential for reducing mercury pollution from dental amalgam and batteries. Final report prepared for the European Commission – DG ENV.

Bishop, K., C. Allan, L. Bringmark, E. Garcia, S. Hellsten, L. Högbom, K. Johansson, A. Lomander, M. Meili, J. Munthe, M. Nilsson, P. Porvari, U. Skyllberg, R. Sørensen, T. Zetterberg and S. Åkerblom, 2009. The effects of forestry on Hg bioaccumulation in nemoral/boreal waters and recommendations for good silvicultural practice. Ambio, 38:373-380.

Blanchard, P., F. Froude, J. Martin, H. Dryfhout-Clark and J. Woods, 2002. Four years of continuous total gaseous mercury (TGM) measurements at sites in Ontario, Canada. Atmospheric Environment, 36:3735-3743.

Bodaly, R.A., R.E. Hecky and R.J.P. Fudge, 1984. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Canadian Journal of Fisheries and Aquatic Sciences, 41:682-691.

Bodaly, R.A., V.L. St.Louis, M.J. Paterson, R.J.P. Fudge, B.D. Hall, D.M. Rosenberg and J.W.M. Rudd, 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. In: Sigel, A. and H. Sigel (Eds.). Mercury and its Effects on Environment and Biology, pp. 257-289. Marcel Dekker.

Bodaly, R.A.D., W.A. Jansen, A.R. Majewski, R.J.P. Fudge, N.E. Strange, A.J. Derksen and D.J. Green, 2007. Postimpoundment time course of increased mercury concentrations in fish in hydroelectric reservoirs of northern Manitoba, Canada. Archives of Environmental Contamination and Toxicology, 53:379-389.

Bonasoni, P., P. Laj, A. Marinoni and 23 others, 2010. Atmospheric Brown Clouds in the Himalayas: first two years of continuous observations at the Nepal Climate Observatory-Pyramid (5079 m). Atmospheric Chemistry and Physics, 10:7515-7531.

Booth, S. and D. Zeller, 2005. Mercury, food webs, and marine mammals: Implications of diet and climate change for human health. Environmental Health Perspectives, 113:521-526.

Born, E.W., A. Renzoni and R. Dietz, 1991. Total mercury in hair of polar bears (*Ursus maritimus*) from Greenland and Svalbard. Polar Research, 9:113-120.

Boudala, F.S., I. Folkins, S. Beauchamp, R. Tordon, J. Neima and B. Johnson, 2000. Mercury flux measurements over air and water in Kejimkujik National Park, Nova Scotia. Water, Air and Soil Pollution, 122:183-202.

Bowman, K.L., C.R. Hammerschmidt and C.H. Lamborg, 2012. U.S. GEOTRACES: distribution of mercury species across a zonal section of the North Atlantic. Presentation at the Ocean Sciences Meeting, Salt Lake City, UT, USA. (as cited by Mason et al., 2012).

Branfireun, B.A., D.P. Krabbenhoft, H. Hintelmann, R.J. Hunt, J.P. Hurley and J.W.M. Rudd, 2005. Speciation and transport of newly deposited mercury in a boreal forest wetland: a stable mercury isotope approach. Water Resources Research, 41:W06016.

BREF, 2006. Reference Document on Best Available Techniques for Large Combustion Plants. European Commission, July 2006. Online at: http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf

BREF, 2009. Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries. European Commission, Draft (July 2009). Online at: http://eippcb.jrc.ec.europa.eu/reference/BREF/nfm_2d_07-2009_public.pdf

BREF, 2010. Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries. European Commission, May 2010. Online at: http://eippcb.jrc.es/reference/BREF/clm_bref_0510.pdf

BREF, 2012a. 2012. Best Available Techniques (BAT) Reference Document for Iron and Steel ProductionIndustrial Emissions Directive 2010/75/EU. (Integrated Pollution Prevention and Control). European Commission, March, 2012. Online at: http://eippcb.jrc.ec.europa.eu/reference/BREF/IS_Adopted_03_2012.pdf

BREF, 2012b. [Draft] Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas. Industrial Emissions Directive 2010/75/EU. (Integrated Pollution Prevention and Control). European Commission, Draft 2 (March 2012). Online at: http://eippcb.jrc.ec.europa.eu/reference/BREF/REF_D2%20_032012.pdf

Brenninkmeijer, C.A.M., P. Crutzen, F. Boumard and 47 others, 2007. Civil Aircraft for the regular investigation of the atmosphere based on an instrumented container: The new CARIBIC system. Atmospheric Chemistry and Physics, 7:4953-4976.

Brigham, M.E., D.A. Wentz, G.R. Aiken and D.K. Krabbenhoft, 2009. Mercury cycling in stream ecosystems. 1. Water column chemistry and transport. Environmental Science and Technology, 43:2720-2725.

Brown, R.J.C., M.K. Burdon, A.S. Brown and K.-H. Kim, 2012. Assessment of pumped mercury vapour adsorption tubes as passive samplers using a micro-exposure chamber. Journal of Environmental Monitoring, 14:2456-2463.

Bullock, O.R. Jr. and K.A. Brehme, 2002. Atmospheric mercury simulation using the CMAQ model: formulation description and analysis of wet deposition results. Atmospheric Environment, 36:2135-2146.

Bullock, O., J. Russell, D. Atkinson, T. Braverman, K. Civerolo, A. Dastoor, D. Davignon, J.-Y. Ku, K. Lohman, T.C. Myers, R.J. Park, C. Seigneur, N.E. Selin, G. Sistla and K. Vijayaraghavan, 2008. The North American Mercury Model Intercomparison Study (NAMMIS): Study description and model-to-model comparisons. Journal of Geophysical Research, 113:D17310.

Bullock, O.R.J., D. Atkinson, T. Braverman, K. Civerolo, A. Dastoor, D. Davignon, J.Y. Ku, K. Lohman, T.C. Myers, R.J. Park, C. Seigneur, N.E. Selin, G. Sistla and K. Vijayaraghavan, 2009. An analysis of simulated wet deposition of mercury from the North American Mercury Model Intercomparison Study. Journal of Geophysical Research, 114:D08301.

Butler, T.J., M.D. Cohen, F.M. Vermeylen, G.E. Likens, D. Schmeltz and R.S. Artz, 2008. Regional precipitation mercury trends in the eastern USA, 1998–2005: Declines in the Northeast and Midwest, no trend in the Southeast. Atmospheric Environment, 42:1582-1592.

Calvert, J.G. and S.E. Lindberg, 2005. Mechanisms of mercury removal by $O_3$ and OH in the atmosphere. Atmospheric Environment, 39:3355-3367.

Campbell, L.M., R.J. Norstrom, K.A. Hobson, D.C.G. Muir, S. Backus and A. Fisk, 2005. Mercury and other trace elements in a pelagic Arctic marine food web (Northwater Polynya, Baffin Bay). Science of the Total Environment, 351-352:247-263.

Carrie, J., G.A. Stern, H. Sanei, R.W. Macdonald and F. Wang, 2012. Determination of mercury biogeochemical fluxes in the remote Mackenzie River Basin, northwest Canada, using speciation of sulfur and organic carbon. Applied Geochemistry, 27:815-824.

Carroll, R.W.H., J.J. Warwick, A.I. James and J.R. Miller, 2004. Modeling erosion and overbank deposition during extreme flood conditions on the Carson River, Nevada. Journal of Hydrology, 297:1-21.

CCICED, 2011. Special Policy Study on Mercury Management in China. China Council for International Cooperation on Environment and Development (CCICED) Annual General Meeting. Online at: http://www.cciced.net/encciced/policyresearch/report/201205/P020120529368288424164.pdf

CEC, 2011. North American Power Plant Air Emissions. Commission for Environmental Cooperation.

CEMBUREAU, 2010. Mercury in the Cement Industry. By: Renzoni, R., C. Ullrich, S. Belboom and A. Germain. The European Cement Association (CEMBUREAU). Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/A_Inventories/CEMENT%20Industry%20-%20Hg%20report%20CEMBUREAU%20April%202010.pdf

Chand, D., D. Jaffe, E. Prestbo, P.C. Swartzendruber, W. Hafner, P. Weiss-Penzias, S. Kato, A. Takami, S. Hatakeyama and Y. Kajii, 2008. Reactive and particulate mercury in the Asian marine boundary layer. Atmospheric Environment, 42:7988-7996.

Choe, K.-Y., G.A. Gill, R.D. Lehman, S. Han, W.A. Heim and K.H. Coale, 2004. Sediment–water exchange of total mercury and monomethyl mercury in the San Francisco Bay-Delta. Limnology and Oceanography, 49:1512-1527.

Choi, H.-D., T.J. Sharac and T.M. Holsen, 2008. Mercury deposition in the Adirondacks: A comparison between precipitation and throughfall. Atmospheric Environment, 42:1818-1827.

Chongprasith, P., W. Utoomprurkporn, E. Praekulvanich and P. Sangwichit, 2001. Mercury Assessment in Thailand. Prepared by Pollution Control Department, Ministry of Science, Technology and Environment, Thailand. Submitted to United Nations Environment Programme (UNEP) Chemicals.

Ci, Z., X. Zhang, Z. Wang and Z. Niu, 2011. Atmospheric gaseous elemental mercury (GEM) over a coastal/rural site downwind of East China: Temporal variation and long-range transport. Atmospheric Environment, 45:2480-2487.

CIA, 2012. World Factbook. List of GDP PPP per country. Online at: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank.html

Cohen, M., R. Artz, R. Draxler, P. Miller, L. Poissant, D. Niemi, D. Ratté, M. Deslauriers, R. Duval, R. Laurin, J. Slotnick, T. Nettesheim and J. McDonald, 2004. Modeling the atmospheric transport and deposition of mercury to the Great Lakes. Environmental Research, 95:247-265.

Cole, A.S. and A. Steffen, 2010. Trends in long-term gaseous mercury observations in the Arctic and effects of temperature and other atmospheric conditions. Atmospheric Chemistry and Physics, 10:4661-4672.

Cole, A.S., A. Steffen, K. Aspmo Pfaffhuber, T. Berg, M. Pilote, L. Poissant, R. Tordon and H. Hung, 2012. Ten-year trends of atmospheric mercury in the high Arctic compared to Canadian sub-Arctic and mid-latitude sites. Atmospheric Chemistry and Physics Discussions, 12:20209-20237.

Coquery, M. and D. Cossa, 1995. Mercury speciation in surface waters of the North Sea. Netherlands Journal of Sea Research, 34:245-257.

Corbitt, E.S, D.J. Jacob, C.D. Holmes, D.G. Streets and E.M. Sunderland, 2011. Global source-receptor relationships for mercury deposition under present-day and 2050 emissions scenarios. Environmental Science and Technology, 45:10477-10484.

Cossa, D., P. Michel, J. Noel and D. Auger, 1992. Vertical mercury profile in relation to arsenic, cadmium and copper at the eastern North Atlantic ICES reference station. Oceanologica Acta, 15:603-608.

Cossa, D., M. Coquery, J.-M. Martin and C. Gobell, 1996. Mercury fluxes at the ocean margins. In: Baeyens, W., R. Ebinghaus and O. Vasiliev (Eds.). Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances, pp. 229-248. Kluwer Academic Publishers.

Cossa, D., J.-M. Martin, K. Takayanagi and J. Sanjuan, 1997. The distribution and cycling of mercury species in the western Mediterranean. Deep-Sea Research, 44:721-740.

Cossa, D., B. Averty and N. Pirrone, 2009. The origin of methylmercury in open Mediterranean waters. Limnology and Oceanography, 54:837-844.

Cossa, D., L.-E. Heimbürger, D. Lannuzel, S.R. Rintoul, E.C.V. Butler, A.R. Bowie, B. Averty, R.J. Watson and T. Remenyi, 2011. Mercury in the Southern Ocean. Geochimica et Cosmochimica Acta, 75:4037-4052.

Costa, M.F., W.M. Landing, H.A. Kehrig, M. Barletta, C.D. Holmes, P.R.G. Barrocas, D.C. Evers, D.G. Buck, A.C. Vasconcellos, S.S. Hacon, J.C. Moreira and O. Malm, 2012. Mercury in tropical and subtropical coastal environments. Environmental Research, 119:88-100.

Covelli, S., J. Faganeli, M. Horvat and A. Brambati, 1999. Porewater distribution and benthic flux measurements of mercury and methylmercury in the Gulf of Trieste (northern Adriatic Sea). Estuarine, Coastal and Shelf Science, 48:415-428.

Crespo-Medina, M., A.D. Chatziefthimiou, N.S. Bloom, G.W. Luther, D.D. Wright, J.R. Reinfelder, C. Vetriani and T. Barkay, 2009. Adaptation of chemosynthetic microorganisms to elevated mercury concentrations in deep-sea hydrothermal vents. Limnology and Oceanography, 54:41-49.

CSGB, various dates. International Cremation Statistics (annual data, 1996 to 2009). The Cremation Society of Great Britain (CSGB). Online at: www.srgw.demon.co.uk/CremSoc4/Stats/index.html#International2009

CSI, 2005. Guidelines for the Selection and Use of Fuels and Raw Materials in the Cement Manufacturing Process. Cement Sustainability Initiative (CSI). Online at: www.wbcsdcement.org/index.php/key-issues/fuels-and-materials/guidelines-for-selection

Dabrowski, J.M., P.J. Ashton, J.J. Leaner and R.P. Mason, 2008. Anthropogenic mercury emissions in South Africa: Coal combustion in power plants. Atmospheric Environment, 42:6620-6626.

Dai, A. and K.E. Trenberth, 2002. Estimates of freshwater discharge from continents: latitudinal and seasonal variations. Journal of Hydrometeorology, 3:660-683.

Dastoor, A P. and Y. Larocque, 2004. Global circulation of atmospheric mercury: a modeling study. Atmospheric Environment, 38:147-161.

de la Rosa, D.A., T. Volke-Sepúlveda, G. Solórzano, C. Green, R. Tordon and S. Beauchamp, 2004. Survey of atmospheric total gaseous mercury in Mexico. Atmospheric Environment, 38:4839-4846.

Dekov, V.M., 2007. Native Hg-liq. in the metalliferous sediments of the East Pacific Rise (211 S). Marine Geology, 238:107-113.

Dibble, T.S., M.J. Zelie and H. Mao, 2012. Thermodynamics of reactions of ClHg and BrHg radicals with atmospherically abundant free radicals. Atmospheric Chemistry and Physics Discussions, 12:17887-17911.

Dietz, R., F. Riget, E.W. Born, C. Sonne, P. Grandjean, M. Kirkegaard, M.T. Olsen, G. Asmund, A. Renzoni, H. Baagoe and C. Andreasen, 2006a. Trends in mercury in hair of Greenlandic polar bears (*Ursus maritimus*) during 1892-2001. Environmental Science and Technology, 40:1120-1125.

Dietz, R., F. Riget, D. Boertmann, C. Sonne, M.T. Olsen, J. Fjeldsa, K. Falk, M. Kirkegaard, C. Egevang, G. Asmund, F. Wille and S. Moller, 2006b. Time trends of mercury in feathers of West Greenland birds of prey during 1851-2003. Environmental Science and Technology, 40:5911-5916.

Dietz, R., P.M. Outridge and K.A. Hobson, 2009. Anthropogenic contributions to mercury levels in present-day Arctic animals – A review. Science of the Total Environment, 407:6120-6131.

Dietz, R., E.W. Born, F. Rigét, A. Aubail, C. Sonne, R. Drimmie and N. Basu, 2011. Temporal trends and future predictions of mercury concentrations in Northwest Greenland polar bear (*Ursus maritimus*) hair. Environmental Science and Technology, 45:1458-1465.

Dittman, J.A., J.B. Shanley, C.T. Driscoll, G.R. Aiken, A.T. Chalmers and J.E. Towse, 2009. Ultraviolet absorbance as a proxy for total dissolved mercury in streams. Environmental Pollution, 157:1953-1956.

Dittman, J.A., J.B. Shanley, C.T. Driscoll, G.R. Aiken, A.T. Chalmers, J.E. Towse and P. Selvendiran, 2010. Mercury dynamics in relation to dissolved organic carbon concentration and quality during high flow events in three northeastern U.S. streams. Water Resources Research 46, W07522.

Dommergue, A., F. Sprovieri, N. Pirrone, R. Ebinghaus, S. Brooks, J. Courteaud and C.P. Ferrari, 2010. Overview of mercury measurements in the Antarctic troposphere. Atmospheric Chemistry and Physics, 10:3309-3319.

Dommergue, A., C.P. Ferrari, O. Magand, M. Barret, L. Gratz, N. Pirrone and F. Sprovieri, 2012. Monitoring of gaseous elemental mercury in central Antarctica at Dome Concordia. Presented at the 16th International Conference on Heavy Metals in the Environment, Rome, Italy.

Driscoll, C.T., Y.-JI. Han, C.Y. Chen, D.C. Evers, K.F. Lambert, T.M. Holsen, N.C. Kamman and R.K. Munson, 2007. Mercury contamination in forest and freshwater ecosystems in the northeastern United States. BioScience, 57:17-28.

Durnford, D.A., A.P. Dastoor, A.O. Steen, T. Berg, A. Ryzhkov, D. Figueras-Nieto, L.R. Hole, K.A. Pfaffhuber and H. Hung, 2012. How relevant is the deposition of mercury onto snowpacks? – Part 1: A statistical study on the impact of environmental factors. Atmospheric Chemistry and Physics Discussions, 12:387-439.

Dvonch, J., J. Graney, F. Marsik, G. Keeler and R. Stevens, 1998. An investigation of source-receptor relationships for mercury in south Florida using event precipitation data. Science of the Total Environment, 213:95-108.

Dvonch, J.T., J.R. Graney, G.J. Keeler and R.K. Stevens, 1999. Use of elemental tracers to source apportion mercury in South Florida precipitation. Environmental Science and Technology, 33:4522-4527.

Dvonch, J.T., M. Morishita, N.L. Hall, J.A. Barres and G.J. Keeler, 2012. Assessing the sources of atmospheric mercury wet deposition in Florida, USA. Presented at the 16th International Conference on Heavy Metals in the Environment.

E-PRTR, 2012. European Pollutant Release and Transfer Register (E-PRTR). Online at: http://prtr.ec.europa.eu/ and http://prtr.ec.europa.eu/PollutantReleases.aspx.

Ebinghaus, R. and F. Slemr, 2000. Aircraft measurements of atmospheric mercury over southern and eastern Germany. Atmospheric Environment, 34:895-903.

Ebinghaus, R., H.H. Kock, C. Temme, J.W. Einax, A.G. Lowe, A. Richter, J.P. Burrows and W.H. Schroeder, 2002. Antarctic springtime depletion of atmospheric mercury. Environmental Science and Technology, 36:1238-1244.

Ebinghaus, R., F. Slemr, C.A.M. Brenninkmeijer, P. van Velthoven, A. Zahn, M. Hermann, D. O'Sullivan and D.E. Oram, 2007. Emissions of gaseous mercury from biomass burning in South America in 2005 observed during CARIBIC flights. Geophysical Research Letters, 34:L08813.

Ebinghaus, R., C. Banic, S. Beauchamp, D. Jaffe, H.H. Kock, N. Pirrone, L. Poissant, F. Sprovieri and P.S. Weiss-Penzias, 2009. Spatial coverage and temporal trends of land-based atmospheric mercury measurements in the Northern and Southern Hemispheres. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 223-291. Springer.

Ebinghaus, R., S. Jennings, H. Kock, R. Derwent, A. Manning and T. Spain, 2011. Decreasing trends in total gaseous mercury observations in baseline air at Mace Head, Ireland from 1996 to 2009. Atmospheric Environment, 45:3475-3480.

Ebinghaus, R., A. Weigelt, C. Brenninkmeijer, F. Slemr and T. Schuck, 2012. Upper air observations of mercury concentrations performed within GMOS. GMOS WP5 First Progress Report, European Commission.

EC, 2012. Study on the potential for reducing mercury pollution from dental amalgam and batteries. Final Report. European Commission - DG ENV. 11 July 2012. Online at: http://ec.europa.eu/environment/chemicals/mercury/pdf/Final_report_11.07.12.pdf

Eide, R. and G.R. Wesenberg, 1993. Mercury contents of indicators and target organs in rats after long-term, low-level, mercury-vapor exposure. Environmental Research, 61:212-222.

Eide, R., G.R. Wesenberg and G. Fosse, 1993. Mercury in primary teeth in preindustrial Norway. Scandinavian Journal of Dental Research, 101:1-4.

EMEP/EEA, 2009. EMEP/EEA air pollutant emission inventory guidebook – 2009. Technical report No 9/2009. Available at: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009

Engineering Toolbox, 2012. Fuels – Higher Calorific Values. Online at: www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

Environment Canada, 2012. National Pollution Release Inventory (NPRI) 2010. Online at: www.ec.gc.ca/inrp-npri

Ericksen, J.A. and M.S. Gustin, 2004. Foliar exchange of mercury as a function of soil and air mercury concentrations. Science of the Total Environment, 324:271-279.

Ericksen, J.A., M.S. Gustin, D.E. Schorran, D.W. Johnson, S.E. Lindberg and J.S. Coleman, 2003. Accumulation of atmospheric mercury in forest foliage. Atmospheric Environment, 37:1613-1622.

ESY, 2011. Energy Statistics (2008) Yearbook, United Nations.

Evers, D.C., Y.-JI Han, C.T. Driscoll, N.C. Kamman, M.W. Goodale, K.F. Lambert, T.M. Holsen, C.Y. Chen, T.A. Clair and T. Butler, 2007. Biological mercury hotspots in the northeastern United States and southeastern Canada. BioScience, 57:29-43.

Evers, D.C., R.P. Mason, N.C. Kamman, C.Y. Chen, A.L. Bogomolni, D.L. Taylor, C.R. Hammerschmidt, S.H. Jones, N.M. Burgess, K. Munney and K.C. Parsons, 2008. Integrated mercury monitoring program for temperate estuarine and marine ecosystems on the North American Atlantic coast. EcoHealth, 5:426-441.

Faïn, X., D. Obrist, A.G. Hallar, I. Mccubbin and T. Rahn, 2009. High levels of reactive gaseous mercury observed at a high elevation research laboratory in the Rocky Mountains. Atmospheric Chemistry and Physics, 9:8049-8060.

FAO, 2010. Global Forest Resources Assessment 2010. Food and Agriculture Organization of the United Nations, FAO Forestry Paper 163. Online at: www.fao.org/forestry/fra/fra2010/en

Farella, N., M. Lucotte, R. Davidson and S. Daigle, 2006. Mercury release from deforested soils triggered by base cation enrichment. Science of the Total Environment, 368:19-29.

Feller, M.C., 2010. Deforestation and nutrient loading to fresh waters. In: Likens, G. (Ed.). River Ecosystem Ecology: A Global Perspective, pp. 221-291. Academic Press.

Feng, X., L. Shang, S. Wang, S. Tang and W. Zheng, 2004. Temporal variation of total gaseous mercury in the air of Guiyang, China. Journal of Geophysical Research, 109:D03303.

Ferrara, R., B. Mazzolai, H. Edner, S. Svanberg and E. Wallinder, 1998. Atmospheric mercury sources in the Mt. Amiata area, Italy. Science of the Total Environment, 213:13-23.

Ferrara, R., B. Mazzolai, E. Lanzillotta, E. Nucaro and N. Pirrone, 2000a. Volcanoes as emission sources of atmospheric mercury in the Mediterranean basin. Science of the Total Environment, 259:115-121.

Ferrara, R., B. Mazzolai, E. Lanzillotta, Nucaro and N. Pirrone, 2000b. Temporal trends in gaseous mercury evasion from the Mediterranean seawaters. Science of the Total Environment, 259:183-190.

Fekete, B.M., C.J. Vörösmarty and W. Grabs, 2000. Global Composite Runoff Fields Based on Observed River Discharge and Simulated Water Balances. Complex Systems Research Center, University of New Hampshire. UNH-GRDC Composite Runoff Fields v1.0. Online at: www.grdc.sr.unh.edu/.

Finley, B.D., P.C. Swartzendruber and D.A. Jaffe, 2009. Particulate mercury emissions in regional wildfire plumes observed at the Mount Bachelor Observatory. Atmospheric Environment, 43:6074-6083.

Fisher, J.A., D.J. Jacob, A.L. Soerensen, H.M. Amos, A. Steffen and E.M. Sunderland, 2012. Riverine source of Arctic Ocean mercury inferred from atmospheric observations. Nature Geoscience, 5:499-504.

Fitzgerald, W.F. and C.H. Lamborg, 2007. Geochemistry of mercury in the environment. In: Lollar, B.S. (Ed.). Environmental Geochemistry, Treatise on Geochemistry, pp. 1-47. Vol. 9.04, Elsevier.

Fitzgerald, W.F., D.R. Engstrom, C.H. Lamborg, C.M. Tseng, P.H. Balcom and C.R. Hammerschmidt, 2005. Modern and historic atmospheric mercury fluxes in northern Alaska: Global sources and Arctic depletion. Environmental Science and Technology, 39:557-568.

Fitzgerald, W.F., C.H. Lamborg and C.R. Hammerschmidt, 2007. Marine biogeochemical cycling of mercury. Chemical Reviews, 107:641-662.

Friedli, H.R., L.F. Radke, J.Y. Lu, C. Banic, W.R. Leaitch and J.I. MacPherson, 2003. Mercury emissions from burning of biomass from temperate North American forests: laboratory and airborne measurements. Atmospheric Environment, 37:253-267.

Friedli, H., A. Arellano, S. Cinnirella and N. Pirrone, 2009. Initial estimates of mercury emissions to the atmosphere from global biomass burning. Environmental Science and Technology, 43:3507-3513.

Friedli, H.R., A.F. Arellano Jr., F. Geng, C. Cai and L. Pan, 2011. Measurements of atmospheric mercury in Shanghai during September 2009. Atmospheric Chemistry and Physics, 11:3781-3788.

Friess, U., H. Sihler, R. Sander, D. Pohler, S. Yilmaz and U. Platt, 2001. The vertical distribution of BrO and aerosols in the Arctic: Measurements by active and passive differential optical absorption spectroscopy. Journal of Geophysical Research, 116: D00R04.

Fu, X., X. Feng, W. Zhu, S. Wang and J. Lu, 2008a. Total gaseous mercury concentrations in ambient air in the eastern slope of Mt. Gongga, south-eastern fringe of the Tibetan plateau, China. Atmospheric Environment, 42:970-979.

Fu, X., X. Feng, W. Zhu, W. Zheng, S. Wang and J.Y. Lu, 2008b. Total particulate and reactive gaseous mercury in ambient air on the eastern slope of the Mt. Gongga area, China. Applied Geochemistry, 23:408-418.

Fu, X.W., X. Feng, Z.Q. Dong, R.S. Yin, J.X. Wang, Z.R. Yang and H. Zhang, 2010a. Atmospheric gaseous elemental mercury (GEM) concentrations and mercury depositions at a high-altitude mountain peak in south China. Atmospheric Chemistry and Physics, 10:2425-2437.

Fu, X.W., X.B. Feng, W.Z. Zhu, S. Rothenberg, H. Yao, N. Liu and R.S. Yin, 2010b. Elevated atmospheric deposition and dynamics of mercury in a remote upland forest of Southwestern China. Environmental Pollution, 158:2324-2433.

Fu, X., X. Feng, G. Qiu, L. Shang and H. Zhang, 2011. Speciated atmospheric mercury and its potential source in Guiyang, China. Atmospheric Environment, 45:4205-4212.

Fu, X.W., X. Feng, L.H. Shang, S.F. Wang and H. Zhang, 2012a. Two years of measurements of atmospheric total gaseous mercury (TGM) at a remote site in Mt. Changbai area, Northeastern China. Atmospheric Chemistry and Physics, 12:4215-4226.

Fu, X.W., X. Feng, P. Liang, Deliger, H. Zhang, J. Ji and P. Liu, 2012b. Temporal trend and sources of speciated atmospheric mercury at Waliguan GAW station, Northwestern China. Atmospheric Chemistry and Physics, 12:1951-1964.

Fukuda, N., M. Takaoka, S. Doumoto, K. Oshita, S. Morisawa and T. Mizuno, 2011. Mercury emission and behavior in primary ferrous metal production. Atmospheric Environment, 45:3685-3691.

GAO, 2009. Preliminary observations on the effectiveness and costs of mercury control technologies at coal-fired power plants. Testimony before the subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works, U. S. Senate. United States Government Accountability Office. GAO-09-86T.

Garcia, E. and R. Carignan, 2000. Mercury concentrations in northern pike (*Esox lucius*) from boreal lakes with logged, burned, or undisturbed catchments. Canadian Journal of Fisheries and Aquatic Sciences, 57:129-135.

Gårdfeldt, K. and M. Jonsson, 2003. Is bimolecular reduction of Hg(II) complexes possible in aqueous systems of environmental importance. Journal of Physical Chemistry A, 107:4478-4482.

Gårdfeldt, K., J. Sommar, R. Ferrara, C. Ceccarini, E. Lanzillotta, J. Munthe, I. Wängberg, O. Lindqvist, N. Pirrone, F. Sprovieri, E. Pesenti and D. Strömberg, 2003. Evasion of mercury from coastal and open waters of the Atlantic Ocean and the Mediterranean Sea. Atmospheric Environment, 37:73-84.

Gbor, P.K., D. Wen, F. Meng, F. Yang, B. Zhang and J.J. Sloan, 2006. Improved model for mercury emission, transport and deposition. Atmospheric Environment, 40:973-983.

German, C.R. and K.L. Von Damm, 2004. Hydrothermal processes. In: Holland, H.D. and K.K. Turekian (Eds.). Treatise on Geochemistry, pp. 181-222. Elsevier.

Gill, G.A., N.S. Bloom, S. Cappellino, C.T. Driscoll, C. Dobbs, L. McShea, R.P. Mason and J.W.M. Rudd, 1999. Sediment–water fluxes of mercury in Lavaca Bay, Texas. Environmental Science and Technology, 33:663-669.

Gilmour, C.C., E.A. Henry and R. Mitchell, 1992. Sulfate stimulation of mercury methylation in freshwater sediments. Environmental Science and Technology, 26:2281-2288.

Giurco, D., T. Prior, G.M. Mudd, L. Mason and J. Behrisch, 2010. Peak Minerals in Australia: A Review of Changing Impacts and Benefits. Institute for Sustainable Futures, University of Technology, Sydney, Australia. As cited by: UNEP, 2011. Decoupling natural resource use and environmental impacts from economic growth. A Report of the Working Group on Decoupling to the International Resource Panel.

Gobeil, C., R.W. Macdonald and J.N. Smith, 1999. Mercury profiles in sediments of the Arctic Ocean basins. Environmental Science and Technology, 33:4194-4198.

Goodsite, M.E., J.M.C. Plane and H. Skov, 2012. Correction to a theoretical study of the oxidation of Hg0 to HgBr2 in the troposphere. Environmental Science and Technology, 46:5262-5262.

Gratz, L.E. and G.J. Keeler, 2011. Sources of mercury in precipitation to Underhill, VT. Atmospheric Environment, 45:5440-5449.

Gratz, L.E., G. Keeler and E.K. Miller, 2009. Long-term relationships between mercury wet deposition and meteorology. Atmospheric Environment, 43:6218-6229.

Gratz, L.E., G.J. Keeler, J.D. Blum and L.S. Sherman, 2010. Isotopic composition and fractionation of mercury in Great Lakes precipitation and ambient air. Environmental Science and Technology, 44:7764-7770.

Gratz, L.E., G.J. Keeler, F.J. Marsik, J.A. Barres and J.T. Dvonch, 2013a. Atmospheric transport of speciated mercury across southern Lake Michigan: Influence from emission sources in the Chicago/Gary urban area. Science of the Total Environment, 448:84-95.

Gratz, L.E., G.J. Keeler, M. Morishita, J.A. Barres and J.T. Dvonch, 2013b. Assessing the emission sources of atmospheric mercury in wet deposition across Illinois, USA. Science of the Total Environment, 448:120-131.

Gratz, L.E., G. Esposito, S. Dalla Torre, F. Cofone, N. Pirrone and F. Sprovieri, 2012. First measurements of ambient total gaseous mercury (TGM) at the Ev-K2-CNR pyramid observatory in Nepal. Presented at the 16th International Conference on Heavy Metals in the Environment, Rome, Italy.

Grigal, D.F., 2002. Inputs and outputs of mercury from terrestrial watersheds: a review. Environmental Reviews, 10:1-39.

Grigal, D., 2003. Mercury sequestration in forests and peatlands: a review. Journal of Environmental Quality, 32:393- 405.

Grimalt, J.O., J. Catalan, P. Fernandez, B. Piña and J. Munthe, 2010. Distribution of persistent organic pollutants and mercury in freshwater ecosystems under changing climate conditions. In, Kernan, M., R.W. Battarbee and B. Moss (Eds.). Climate Change Impacts on Freshwater Ecosystems, Chapter 8, pp. 180-202. Wiley-Blackwell.

Guentzel, J.L., W.M. Landing, G.A. Gill and C.D. Pollman, 2001. Processes influencing rainfall deposition of mercury in Florida. Environmental Science and Technology, 35:863-873.

Guo, Y.N., X.B. Feng, Z.G. Li, T.R. He, H.Y. Yan and B. Meng, 2008. Distribution and wet deposition fluxes of total and methyl mercury in Wujiang reservoir Basin, Guizhou, China. Atmospheric Environment, 42:7096-7103.

Gustin, M.S., S. Lindberg, F. Marsik and 23 others, 1999. Nevada STORMS project: Measurement of mercury emissions from naturally enriched surfaces, Journal of Geophysical Research, 104(D17):21831-21844.

Gustin, M.S., S.N. Lyman, P. Kilner and E. Prestbo, 2011. Development of a passive sampler for gaseous mercury. Atmospheric Environment, 45:5805-5812.

Gustin, M.S., P.S. Weiss-Penzias and C. Peterson, 2012. Investigating sources of gaseous oxidized mercury in dry deposition at three sites across Florida, USA. Atmospheric Chemistry and Physics, 12:9201-9219.

GWSP, 2008. GWSP Digital Water Atlas (2008). Map 52: Change in Runoff due to Deforestation (V1.0). Global Water System Project (GWSP). Online at http://atlas.gwsp.org

Hall, B., 1995. The gas phase oxidation of elemental mercury by ozone. Water, Air, and Soil Pollution, 80:301-315.

Hall, F.G., E.B. Colstoun, G.J. Collatz, D. Landis, P. Dirmeyer, A. Betts, G. Huffman, L. Bounoua and B. Meeson, 2006. The ISLSCP Initiative II

Global Datasets: Surface boundary conditions and atmospheric forcings for land-atmosphere studies. Journal of Geophysical Research, 111: D22S01.

Hall, N., J.T. Dvonch, F. Marsik, M. Landis and G. Keeler, 2011. Comparison of the spatial variability of wet and dry atmospherically deposited mercury measured at urban/industrial and background areas of Southeast Michigan. Presented at the 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia.

Hammerschmidt, C.R. and K.L. Bowman, 2012. Vertical methylmercury distribution in the subtropical North Pacific Ocean. Marine Chemistry, 132/33:77-82.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2004. Geochemical controls on the production and distribution of methylmercury in near-shore marine sediments. Environmental Science and Technology, 38:1487-1495.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2005. Methylmercury in mosquitoes related to atmospheric deposition and contamination. Environmental Science and Technology, 39:3034-3039.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2006a. Methylmercury cycling in sediments on the continental shelf of southern New England. Geochimica et Cosmochimica Acta, 70:918-930.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2006b. Bioaccumulation and trophic transfer of methylmercury in Long Island Sound. Archives of Environmental Contamination and Toxicology, 51:416-424.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2006c. Methylmercury in freshwater fish linked to atmospheric mercury deposition. Environmental Science and Technology, 40:7764-7770.

Hammerschmidt, C.R. and W.F. Fitzgerald, 2008. Sediment–water exchange of methylmercury determined from shipboard benthic flux chambers. Marine Chemistry, 109:86-97.

Hammerschmidt, C.R., W.F. Fitzgerald, C.H. Lamborg, P.H. Balcom and P.T. Visscher, 2004. Biogeochemistry of methylmercury in sediments of Long Island Sound. Marine Chemistry, 90:31-52.

Hammerschmidt, C.R., W.F. Fitzgerald, C.H. Lamborg, P.H. Balcom and C.-M. Tseng, 2006. Biogeochemical cycling of methylmercury in lakes and tundra watersheds of arctic Alaska. Environmental Science and Technology, 40:1204-1211.

Hammerschmidt, C.R., W.F. Fitzgerald, P.H. Balcom and P.T. Visscher, 2008. Organic matter and sulfide inhibit methylmercury production in sediments of New York/New Jersey Harbor. Marine Chemistry, 109:165-182.

Han, Y.-J., T.M. Holsen, S.-O. Lai, P.K. Hopke, S.-M. Yi, W. Liu, J. Pagano, L. Falanga, M. Milligan and C. Andolina, 2004. Atmospheric gaseous mercury concentrations in New York State: relationships with meteorological data and other pollutants. Atmospheric Environment, 38:6431-6446.

Harris, R.C., J.W.M. Rudd, M. Almyot and 21 others, 2007. Whole ecosystem study shows rapid fish-mercury response to changes in mercury deposition. Proceedings of the National Academy of Sciences of the United States of America, 104:16586-16591.

Hecky, R.E., D.J. Ramsey, R.A. Bodaly and N.E. Strange, 1991. Increased methylmercury contamination in fish in newly formed freshwater reservoirs. In: Suzuki T, N. Imura and T.W. Clarkson (Eds.). Advances in Mercury Toxicology, pp. 33-52. Plenum Press.

Hedgecock, I.M. and N. Pirrone, 2004. Chasing quicksilver: Modeling the atmospheric lifetime of Hg-(g)(0) in the marine boundary layer at various latitudes. Environmental Science and Technology, 38:69-76.

Hedgecock, I.M., N. Pirrone, G.A. Trunfio and F. Sprovieri, 2006. Integrated mercury cycling, transport, and air-water exchange (MECAWEx) model. Journal of Geophysical Research, 111:D20302.

Hedgecock, I.M., N. Pirrone and F. Sprovieri, 2008. Chasing quicksilver northward: mercury chemistry in the Arctic troposphere. Environmental Chemistry, 5:131-134.

Heimburger, L.E., D. Cossa, J.-C. Marty, C. Migon, B. Averty, A. Dufour and J. Ras, 2010. Methyl mercury distributions in relation to the presence of nano- and picophytoplankton in an oceanic water column (Ligurian Sea, North-Western Mediterranean). Geochimica et Cosmochimica Acta, 74:5549-5559.

Herut, B., H. Hornung, N. Kress and Y. Cohen, 1996. Environmental relaxation in response to reduced contaminant input: the case of mercury pollution in Haifa Bay, Israel. Marine Pollution Bulletin, 32:366-373.

Hines, M.E., M. Horvat, J. Faganeli, J.-C.J. Bonzongo, T. Barkay, E.B. Major, K.J. Scott, E.A. Bailey, J.J. Warwick and W.B. Lyons, 2000. Mercury biogeochemistry in the Idrija river, Slovenia from above the mine into the Gulf Trieste. Environmental Research, 83:129-139.

Hines, M.E., J. Faganelli, I. Adatto and M. Horvat, 2006. Microbial mercury transformations in marine, estuarine and freshwater sediment downstream of the Idrija Mercury Mine, Slovenija. Applied Geochemistry, 21:1924-1939.

Hines, M.E., E.N. Poitras, S. Covelli, J. Faganelli, A. Emili, S. Žižek and M. Horvat, 2012. Mercury methylation and demethylation in Hg-contaminated lagoon sediments (Marano & Grado Lagoons, Italy). Estuarine, Coastal and Shelf Science, 113:85-95.

Hissler, C. and J.-L. Probst, 2006. Chloralkali industrial contamination and riverine transport of mercury: Distribution and partitioning of mercury between water, suspended matter, and bottom sediment of the Thur River, France. Applied Geochemistry, 21:1837-1854.

Holloway, T., C. Voigt, J. Morton, S.N. Spak, A.P. Rutter and J.J. Schauer, 2012. An assessment of atmospheric mercury in the Community Multiscale Air Quality (CMAQ) model. Atmospheric Chemistry and Physics Discussions, 12:2131-2166.

Hollweg, T.A., C.C. Gilmour and R.P. Mason, 2009. Methylmercury production in sediments of Chesapeake Bay and the mid-Atlantic continental margin. Marine Chemistry, 114:86-101.

Hollweg, T.A., C.C. Gilmour and R.P. Mason, 2010. Mercury and methylmercury cycling in sediments of the mid-Atlantic continental shelf and slope. Limnology and Oceanography, 55:2703-2722.

Holmes, C.D., D.J. Jacob and X. Yang, 2006. Global lifetime of elemental mercury against oxidation by atomic bromine in the free troposphere. Geophysical Research Letters, 33:L20808.

Holmes, C.D., D.J. Jacob, R.P. Mason and D.A. Jaffe, 2009. Sources and deposition of reactive gaseous mercury in the marine atmosphere. Atmospheric Environment, 43:2278-2285.

Holmes, C., D. Jacob, E. Corbitt, J. Mao, X. Yang, R. Talbot and F. Slemr, 2010a. Global atmospheric model for mercury including oxidation by bromine atoms. Atmospheric Chemistry and Physics, 10:12037-12057.

Holmes, C.D., D.J. Jacob, A.L. Soerensen and E.S. Corbitt, 2010b. Global atmospheric budget of mercury including oxidation of Hg(0) by bromine atoms. Geochimica et Cosmochimica Acta, 74:A413-A413.

Holsen, T.M., K.E. Noll, G.C. Fang, W.J. Lee, J.M. Lin and G.J. Keeler, 1992. Dry deposition and particle size distributions measured during Lake Michigan Urban Air Toxics Study. Environmental Science and Technology, 27:1141-1150.

Horvat, M., S. Covelli, J. Faganeli, M. Logar, V. Fajon, R. Rajar, A. Širca and D. Žagar, 1999. Mercury in contaminated coastal environments; a case study: the Gulf of Trieste. Science of the Total Environment, 237/38:43-56.

Horvat, M., J. Kotnik, M. Logar, V. Fajon, T. Zvonaric and N. Pirrone, 2003. Speciation of mercury in surface and deep-sea waters in the Mediterranean Sea. Atmospheric Environment, 37:S93-S108.

Horvat, M., A. Stergaršek, V. Fajon, R. Jaćimović, D. Gibičar, M. Logar, Z. Spirić and J.J. Leonhaeuser, 2007. World-wide remediation of mercury hazard through biotechnology: Case study: mercury in gas and oil industry, IJS-DP 9587, 2007, 24 pp.

Hylander, L.D. and R.B. Herbert, 2008. Global emissions and production of mercury during the pyrometallurgical extraction of nonferrous sulfide ores. Environmental Science and Technology, 42:5971-5977.

Hylander, L. D. and M. Meili, 2003. 500 years of mercury production: global annual inventory by region until 2000 and associated emissions. Science of the Total Environment, 304:13-27.

Hynes, A. J., D.L. Donohoue, M.E. Goodsite and I.M. Hedgecock, 2009. Our current understanding of major chemical and physical processes affecting mercury dynamics in the atmosphere and at the air-water/terrestrial interfaces. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 427-457. Springer.

ICS, 2011. Industrial Commodity Statistics (2008) Yearbook, United Nations.

IEA, 2004. IEA Energy statistics manual. www.iea.org/stats/docs/statistics_manual.pdf

IEA-SB. Statistics and Balances. International Energy Agency (IEA). Online at: www.iea.org/stats/ IEA Energy statistics manual, http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/NRG-2004/EN/NRG-2004-EN.PDF

IFP Energies nouvelles, 2012. Offshore Hydrocarbons. Online at: www.ifpenergiesnouvelles.com/publications/notes-de-synthese-panorama/panorama-2012

IKIMP, 2012. Mercury arising from oil and gas production in the United Kingdom and UK continental shelf. By: Lang, D., M. Gardner and J. Holmes. Integrating Knowledge to Inform Mercury Policy (IKIMP). University of Oxford. 38 pp.

INAC, 2009. Canadian Arctic Contaminants and Health Assessment Report. Northern Contaminants Program, Indian and Northern Affairs Canada, Ottawa.

IPIECA, 2012. Industry input to the UN global mercury treaty negotiations focus on oil and gas. By: Doll, B.E., B.M. Knickerbocker and E. Nucci. The global oil and gas industry association for environmental and social issues (IPIECA).

Jaffe, D., E. Prestbo, P. Swartzendruber, P. Weiss-Penzias, S. Kato, A. Takami, S. Hatakeyama and Y. Kajii, 2005. Export of atmospheric mercury from Asia. Atmospheric Environment, 39:3029-3038.

Japan Ministry of the Environment, 2012. http://www.env.go.jp/press/press.php?serial=15063.

Jeremiason, J.D., L.A. Kanne, T.A. Lacoe, M. Hulting and M.F. Simcik, 2009. A comparison of mercury cycling in Lakes Michigan and Superior. Journal of Great Lakes Research, 35:329-336.

Kabata-Pendias, A. and A.B. Mukherjee, 2007. Trace elements of group 12 (previously group IIb). In: Kabata-Pendias, A. and A.B. Mukherjee (Eds.). Trace Elements from Soil to Human, pp. 283-319. Springer.

Kading, T. and M.E. Andersson, 2011. Mercury and methylmercury distribution in Arctic sediments. Presentation at the 10th International Conference on Mercury as a Global Pollutant. Halifax, NS, Canada, July 2011.

Karpinska (Dombaiová), R., 2005. Mercury and methylmercury in plants from differently contaminated sites in Slovakia. Plant Soil and Environment, 51:456-463.

Keeler, G.J., 1994. Lake Michigan Urban Air Toxics Study. US EPA Office of Research and Development Atmospheric Research and Exposure Assessment Laboratory. EPA/600/SR-94/191.

Keeler, G. and T. Dvonch, 2005. Atmospheric Hg: a decade of observations in the Great Lakes. In: Pirrone, N. and K.R. Mahaffey (Eds.). Dynamics of Mercury Pollution on Regional and Global Scales, pp. 611-636. Springer.

Keeler, G.J., L.E. Gratz and K. Al-Wali, 2005. Long-term atmospheric mercury wet deposition at Underhill, Vermont. Ecotoxicology, 14:71-83.

Keeler, G.J., M.S. Landis, G.A. Norris, E.M. Christianson and J.T. Dvonch, 2006. Sources of mercury wet deposition in Eastern Ohio, USA. Environmental Science and Technology, 40:5874-5881.

Kellerhals, M., S. Beauchamp, W. Belzer, P. Blanchard, F. Froude, B. Harvey, K. McDonald, M. Pilote, L. Poissant, K. Puckett, B. Schroeder, A. Steffen and R. Tordon, 2003. Temporal and spatial variability of total gaseous mercury in Canada: results from the Canadian Atmospheric Mercury Measurement Network (CAMNet). Atmospheric Environment, 37:1003-1011.

Kim, J.P. and W.F. Fitzgerald, 1988. Gaseous mercury profiles in the tropical Pacific Ocean. Geophysical Research Letters, 15:40-43.

Kim, E.-H., R. Mason and C. Bergeron, 2008. A modeling study on methylmercury bioaccumulation and its controlling factors. Ecological Modeling, 218:267-289.

Kim, S.-H., Y.-J. Han, T.M. Holsen and S.-M. Yi, 2009. Characteristics of atmospheric speciated mercury concentrations (TGM, Hg(II) and Hg(p)) in Seoul, Korea. Atmospheric Environment, 43:3267-3274.

Kim, J-H., J-M. Park, S-B. Lee, D.Pudasainee and Y-C. Seo, 2010a. Anthropogenic mercury emission inventory with emission factors and total emission in Korea. Atmospheric Environment, 44:2714-2721.

Kim, J.H., D. Pudasainee, Y.-S. Yoon, S.-U. Son and Y.-C. Seo, 2010b. Studies on speciation changes and mass distribution of mercury in a bituminous coal-fired power plant by combining field data and chemical equilibrium calculation. Industrial and Engineering Chemistry Research, 49:5197-5203.

Kirk, J.L., V.L. St. Louis, H. Hintelmann, I. Lehnherr, B. Else and L. Poissant, 2008. Methylated mercury species in marine waters of the Canadian High and sub-Arctic. Environmental Science and Technology, 42:8367-8373.

Knightes, C.D., E.M. Sunderland, M.C. Barber, J.M. Johnston and R.B. Ambrose Jr., 2009. Application of ecosystem-scale fate and bioaccumulation models to predict fish mercury response times to changes in atmospheric deposition. Environmental Toxicology and Chemistry, 28:881-893.

Kocman, D., T. Kanduč, T. Ogrinc and M. Horvat, 2011. Distribution and partitioning of mercury in a river catchment impacted by former mercury mining activity. Biogeochemistry, 104:183-201.

Kocman, D., M. Horvat, N. Pirrone S. Cinnirella, 2013. Contribution of contaminated sites to the global mercury budget**.** Environmental Research (2013). http://dx.doi.org/10.1016/j.envres.2012.12.011.

Kolker, A., M.L. Olsen, D.P. Krabbenhoft, M.T. Tate and M.A. Engle, 2010. Patterns of mercury dispersion from local and regional emission sources, rural Central Wisconsin, USA. Atmospheric Chemistry and Physics Discussions, 10:1823-1846.

Korzoun,V.I., A.A. Sokolov, M.I,. Budyko, G.P. Voskresensky, A.A. Kalinin, E.S. Konoplyantsev, E.S. Korotkevich and M.I. Lvovich, 1977. Atlas of World Water Balance. UNESCO Press, 36 pp.

Kos, G., A. Ryzhkov, A. Dastoor, J. Narayan, A. Steffen, P.A. Ariya and L. Zhang, 2012. Evaluation of discrepancy between measured and modeled oxidized mercury species. Atmospheric Chemistry and Physics, 12:17245-17293.

Kotnik, J., M. Horvat and T. Dizdarevič, 2005. Current and past mercury distribution in air over the Idrija Hg mine region, Slovenia. Atmospheric Environment, 39:7570-7579.

Kotnik, J., M. Horvat, E. Tessier, N. Ogrinc, M. Monperrus, D. Amomuroux, V. Fajon, D. Gibičar, S. Žižek and F. Sproviere, 2007. Mercury speciation in surface and deep waters of the Mediterranean Sea. Marine Chemistry, 107:13-30.

Kraepiel, A.M.L., K. Keller, H.B. Chin, E.G. Malcolm and F.M.M. Morel, 2003. Sources and variations of mercury in tuna. Environmental Science and Technology, 37:5551-5558.

Kumari, R. (Toxics Link), 2011. Emission Estimate of Passport-Free Heavy Metal Mercury from Indian Thermal Power Plants and Non-Ferrous Smelters. Toxics Link, New Delhi.

Lacerda, L., W.R. Bastos and M.D. Almeida, 2012. The impacts of land use changes in the mercury flux in the Madeira River, Western Amazon. Annals of the Brazilian Academy of Sciences, 84:69-78.

Lado, R.L., T. Hengl and H.I. Reuter, 2008. Heavy metals in European soils: a geostatistical analysis of the FOREGS Geochemical database. Geoderma, 148:189-199.

Lamborg, C., W. Fitzgerald, J. O'Donnell and T. Torgensen, 2002. A non-steady-state compartmental model of global scale mercury biogeochemistry with inter-hemispheric atmospheric gradients. Geochimica et Cosmochimica Acta, 66:1105-1118.

Lamborg, C.H., K.L. Von Damm, W.F. Fitzgerald, C.R. Hammerschmidt and R. Zierenberg, 2006. Mercury and monomethylmercury in fluids from Sea Cliff submarine hydrothermal field, Gorda Ridge. Geophysical Research Letters, 33:L17606.

Landis, M.S. and G.J. Keeler, 1997. Critical evaluation of a modified automatic wet-only precipitation collector for mercury and trace element determinations. Environmental Science and Technology, 31:2610-2615.

Landis, M.S. and G.J. Keeler, 2002. Atmospheric mercury deposition to Lake Michigan during the Lake Michigan mass balance study. Environmental Science and Technology, 36:4518-4524.

Landis, M.S., R.K. Stevens, F. Schaedlich and E.M. Prestbo, 2002. Development and characterization of an annular denuder methodology for the measurement of divalent inorganic reactive gaseous mercury in ambient air. Environmental Science and Technology, 36:3000-3009.

Laurier, F., and R.P. Mason, 2007. Mercury concentration and speciation in the coastal and open ocean boundary layer. Journal of Geophysical Research – Atmospheres, 112:D06302.

Laurier, F.J.G., R.P. Mason, G.A. Gill and L. Whalin, 2004. Mercury distributions in the North Pacific Ocean – 20 years of observations. Marine Chemistry, 90:3-19.

Lehnherr, I., V.L. St. Louis, H. Hintelmann and J.L. Kirk, 2011. Methylation of inorganic mercury in polar marine waters. Nature Geoscience, 4:298-302.

Leitch, D.R., J. Carrie, D. Lean, R.W. Macdonald, G.A. Stern and F. Wang, 2007. The delivery of mercury to the Beaufort Sea of the Arctic Ocean by the Mackenzie River. Science of the Total Environment, 373:178-195.

Li, G., X. Feng, G. Qiu, B. Xiangyang, Y. Li, C. Zhang, D. Wang, L. Shang and Y. Guo, 2008. Environmental mercury contamination of an artisanal zinc smelting area in Weining County, Guizhou, China. Environmental Pollution, 154:21-31.

Li, P., X.B. Feng, G.L. Qiu, L.H. Shang and Z.G. Li, 2009. Mercury pollution in Asia: A review of the contaminated sites. Journal of Hazardous Materials, 168:591-601.

Li, G., X. Feng, Z. Li, G. Qiu, L. Shang, P. Liang, D. Wang and Y. Yang, 2010. Mercury emission to atmosphere from primary Zn production in China. Science of the Total Environment, 408:4607-4612.

Lin, X. and Y. Tao, 2003. A numerical modelling study on regional mercury budget for eastern North America. Atmospheric Chemistry and Physics, 3:535-548.

Lin, C.-J., P. Pongprueksa, S.E. Lindberg, S.O. Pehkonen, D. Byun and C. Jang, 2006. Scientific uncertainties in atmospheric mercury models I: Model science evaluation. Atmospheric Environment, 40:2911-2928.

Lin, C.-J., P. Pongprueksa Jr., S.E. Lindberg, S.O. Pehkonen, C. Jang, T. Braverman and T.C. Ho, 2007. Scientific uncertainties in atmospheric mercury models II: Sensitivity analysis in the CONUS domain. Atmospheric Environment, 41:6544-6560.

Lin, C.-J., L. Pan, D.G. Streets, S.K. Shetty, C. Jang, X. Feng, H.-W. Chu and T.C. Ho, 2010. Estimating mercury emission outflow from East Asia using CMAQ-Hg. Atmospheric Chemistry and Physics, 10:1853-1864.

Lin, C.-J., S.K. Shetty, L. Pan, P. Pongprueksa, C. Jang and H.-W. Chu, 2012. Source attribution for mercury deposition in the contiguous United States: Regional difference and seasonal variation. Journal of the Air and Waste Management Association, 62:52-63.

Lindberg, S.E., S. Brooks, C.-J. Lin, K.J. Scott, M.S. Landis, R.K. Stevens, M. Goodsite and A. Richter, 2002. Dynamic oxidation of gaseous mercury in the Arctic troposphere at polar sunrise. Environmental Science and Technology, 36:1245-1256.

Lindberg, S., R. Bullock, R. Ebinghaus, D. Engstrom, X. Feng, W. Fitzgerald, N. Pirrone, E. Prestbo and C. Seigneur, 2007. A synthesis of progress and uncertainties in attributing the sources of mercury in deposition. AMBIO: A Journal of the Human Environment, 36:19-33.

Lindqvist, O., K. Johansson, L. Bringmark, B. Timm, M. Aastrup, A. Andersson, G. Hovsenius, L. Håkanson, Å. Iverfeldt and M. Meili, 1991. Mercury in the Swedish environment - Recent research on causes, consequences and corrective methods. Water, Air and Soil Pollution, 55: special issue. xiii, 261 p.

Liu, B., G.J. Keeler, J.T. Dvonch, J.A. Barres, M.M. Lynam, F.J. Marsik and J.T. Morgan, 2007. Temporal variability of mercury speciation in urban air. Atmospheric Environment, 41:1911-1923.

Liu, B., L.A. Schaider, R.P. Mason, M.S. Bank, N.N. Rabalais, P.W. Swarzenski, J.P. Shine, T. Hollweg and D.B. Senn, 2009. Disturbance impacts on mercury dynamics in northern Gulf of Mexico sediments. Journal of Geophysical Research, 114:G00C07.

Liu, B., G.J. Keeler, J.T. Dvonch, J.A. Barres, M.M. Lynam, F.J. Marsik and J.T. Morgan, 2010. Urban-rural differences in atmospheric mercury speciation. Atmospheric Environment, 44:2013-2023.

Liu, N., G. Qui, X. Feng, M. Landis, X. Fu and L. Shang, 2011. Distribution characteristics of mercury in precipitation in Guiyang, China. Shengtaixue Zazhi, 30:933-938.

Lodenius, M., A. Seppanen and M. Herranen, 1983. Accumulation of mercury in fish and man from reservoirs in northern Finland. Water, Air and Soil Pollution, 19:237-246.

Lohman, K., C. Seigneur, E. Edgerton and J. Jansen, 2006. Modeling mercury in power plant plumes. Environmental Science and Technology, 40:3848-3854.

Lohman, K., C. Seigneur, M. Gustin and S. Lindberg, 2008. Sensitivity of the global atmospheric cycle of mercury to emissions. Applied Geochemistry, 23:454-466.

LRTAP, 2012. Emissions reporting for 2010 under the UN ECE Convention on Long-range Trans-boundary Air Pollution. Online at: www.unece.org/env/lrtap and www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap

Lu, J.Y. and W.H. Schroeder, 2004. Annual time-series of total filterable atmospheric mercury concentrations in the Arctic. Tellus, 56B:213-222.

Lu, J.Y., W.H. Schroeder, L.A. Barrie, A. Steffen, H.E. Welch, K. Martin, L. Lockhart, R.V. Hunt, G. Boila and A. Richter, 2001. Magnification of atmospheric mercury deposition to polar regions in springtime: the link to tropospheric ozone depletion chemistry. Geophysical Research Letters, 28:3219-3222.

Ludwig, W. and J.-L. Probst, 1998. River sediment discharge to the oceans: Present-day controls and global budgets. American Journal of Science, 296:265-295.

Ludwig, W., J.L. Probst and S. Kempe, 1996. Predicting the oceanic input of organic carbon by continental erosion. Global Biogeochemical Cycles, 10:23-41.

Ludwig, W., P. Amiotte-Suchet, J.L. Probst . 2011a. ISLSCP II Atmospheric Carbon Dioxide Consumption by Continental Erosion. In: Hall, F.G., G. Collatz, B. Meeson, S. Los, E. Brown de Colstoun, and D. Landis (Eds.). ISLSCP Initiative II Collection. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/1019

Ludwig,W., P. Amiotte-Suchet, J.L. Probst. 2011b. ISLSCP II Global River Fluxes of Carbon and Sediments to the Oceans. In: Hall, F.G., G. Collatz, B. Meeson, S. Los, E. Brown de Colstoun, and D. Landis (Eds.). ISLSCP Initiative II Collection. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/1028

Lyman, S.N. and D.A. Jaffe, 2012. Formation and fate of oxidized mercury in the upper troposphere and lower stratosphere. Nature Geoscience, 5:1-4.

Lyman, S.N., M.S. Gustin, E.M. Prestbo and F.J. Marsik, 2007. Estimation of dry deposition of atmospheric mercury in Nevada by direct and indirect methods. Environmental Science and Technology, 41:1970-1976.

Lyman, S.N., D.A. Jaffe and M.S. Gustin, 2010. Release of mercury halides from KCl denuders in the presence of ozone. Atmospheric Chemistry and Physics, 10:8197-8204.

Lynam, M.M. and G.J. Keeler, 2005. Artifacts associated with the measurement of particulate mercury in an urban environment: The influence of elevated ozone concentrations. Atmospheric Environment, 39:3081-3088.

Lynam, M.M. and G.J. Keeler, 2006. Source - receptor relationships for atmospheric mercury in urban Detroit, Michigan. Atmospheric Environment, 40:3144-3155.

MacLeod, M., T.E. McKone and D. Mackay, 2005. A mass balance for mercury in the San Francisco Bay area. Environmental Science and Technology, 39:6721-6729.

Mahaffey, K.R., R.P. Clickner and C.C. Bodurow, 2004. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. Environmental Health Perspectives, 112:562-570.

Mainville, N., J. Webb, M. Lucotte, R. Davidson, O. Betancourt, E. Cueva and D. Mergler, 2006. Decrease of soil fertility and release of mercury following deforestation in the Andean Amazon, Napo River Valley, Ecuador. Science of the Total Environment, 368:88-98.

Maiz, 2008. Informe Final – Inventario Nacional de Liberaciones de Mercurio México 2004 / Final Report - National Inventory of Mercury Releases Mexico 2004. Prepared for: Waste Management Research and Contaminated Sites, Directorate General of the National Environmental Research and Training, National Institute of Ecology, Secretariat of Environment and Natural Resources. Contract INE/ADE-016/2008. November 14, 2008.

Manning, A.J., D.B. Ryall, R.G. Derwent, P.G. Simmonds and S. O'Doherty, 2003. Estimating European emissions of ozone-depleting and greenhouse gases using observations and a modeling back-attribution technique. Journal of Geophysical Research, 108:4405.

Mao, H. and R. Talbot, 2012. Speciated mercury at marine, coastal, and inland sites in New England – Part 1: Temporal variability. Atmospheric Chemistry and Physics, 12:5099-5112.

Markussen, J.M., 1994. Deep seabed mining and the environment: consequences, perceptions, and regulations. In: Bergesen, H.O. and G. Parmann (Eds.), Green Globe Yearbook of International Co-operation on Environment and Development, pp. 31-39. Oxford University Press.

Marsik, F.J., G.J. Keeler and M.S. Landis, 2007. The dry-deposition of speciated mercury to the Florida Everglades: Measurements and modeling. Atmospheric Environment, 41:136-149.

Marvin, C., S. Painter and R. Rossman, 2004. Spatial and temporal patterns in mercury contamination in sediments of the Laurentian Great Lakes. Environmental Research, 95:351-362.

Masekoameng, K.E., J.J. Leaner and J. Dabrowski, 2010. Trends in anthropogenic mercury emissions estimated for South Africa during 2000–2006. Atmospheric Environment, 25:3007-3014.

Mason, R.P., 2009. Mercury emissions from natural processes and their importance in the global mercury cycle. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 173-191. Springer.

Mason, R.P. and J.M. Benoit, 2003. Organomercury compounds in the environment. In: Craig, P.J. (Ed.). Organometallic Compounds in the Environment, pp. 57-99. John Wiley and Sons.

Mason, R.P. and W.F. Fitzgerald, 1990. Alkylmercury species in the equatorial Pacific. Nature, 347:457-459.

Mason, R.P. and W.F. Fitzgerald, 1991. Mercury speciation in open ocean waters. Water, Air Soil and Pollution, 56:779-789.

Mason, R.P. and W.F. Fitzgerald, 1993. The distribution and biogeochemical cycling of mercury in the equatorial Pacific Ocean. Deep-Sea Research I, 40:1897-1924.

Mason, R.P. and G.A. Gill, 2005. Mercury in the marine environment. In: Parsons, M.B. and J.B. Percival (Eds.). Mercury – Sources, Measurements, Cycles and Effects, Chapter 10. Mineralogical Association of Canada Short Course Halifax, Novia Scotia.

Mason, R.P. and G.R. Sheu, 2002. Role of the ocean in the global mercury cycle. Global Biogeochemical Cycles, 16:Article no. 1093.

Mason, R.P. and K.A. Sullivan, 1999. The distribution and speciation of mercury in the South and equatorial Atlantic. Deep-Sea Research II, 46:937-956.

Mason, R.P., W.F. Fitzgerald and F.M.M. Morel, 1994.The biogeochemical cycling of elemental mercury – anthropogenic influences. Geochimica et Cosmochimica Acta, 58:3191-3198.

Mason, R.P., J.R. Reinfelder and F.M.M. Morel, 1996. Uptake, toxicity, and trophic transfer of mercury in a coastal diatom. Environmental Science and Technology, 30:1835-1845.

Mason, R., N. Lawson and K. Sullivan, 1997. Atmospheric deposition to the Chesapeake Bay Watershed – regional and local sources. Atmospheric Environment, 31:3531-3540.

Mason, R.P., K.R. Rolfhus and W.F. Fitzgerald, 1998. Mercury in the North Atlantic. Marine Chemistry, 61:37-53.

Mason, R., N. Lawson and G. Sheu, 2000. Annual and seasonal trends in mercury deposition in Maryland. Atmospheric Environment, 34:1691-1701.

Mason, R.P., N.M. Lawson and G.R. Sheu, 2001. Mercury in the Atlantic Ocean: factors controlling air-sea exchange of mercury and its distribution in the upper waters. Deep-Sea Research II, 48:2829-2853.

Mason, R.P., E.-H. Kim, J. Cornwell and D. Heyes, 2006. An examination of the factors influencing the flux of mercury, methylmercury and other constituents from estuarine sediment. Marine Chemistry, 102:96-110.

Mason, R.P., A.L. Choi, W.F. Fitzgerald, C.R. Hammerschmidt, C.H. Lamborg, A.L. Soerensen and E.M. Sunderland, 2012. Mercury biogeochemical cycling in the ocean and policy implications. Environmental Research, 119:101-117.

Mather, T.A. and D.M. Pyle, 2004. Volcanic emissions of mercury to the atmosphere: global and regional inventories. Comment. Science of the Total Environment, 327:323-329.

Maxson, P., 2009. Mercury Rising: Reducing Global Emissions from Burning Mercury-added Products. Mercury Policy Project. Online at: www.zeromercury.org/phocadownload/Mercury_in_processes/FINAL_MercuryRising_Feb2009.pdf

Mazzi, E., S. Glesmann and A. Bell, 2006. Canada Wide Standards Mercury Measurement Methodologies for Coal-fired Power Plants. Paper # 15. EPRI-EPA-DOE-AW&MA Power Plant Air Pollutant Control 'MEGA' Symposium, August 28-31, 2006, Baltimore, Maryland, USA. Online at: www.ires.ubc.ca/files/2010/05/MazziMegapaper152006final.pdf

McCarty, H.B., K. Miller, R.N. Brent, J. Schofield and R. Rossman, 2004. Results of the Lake Michigan Mass Balance Study: Mercury Data Report. EPA 905 R-01-012. Online at: www.epa.gov/greatlakes/lmmb/results/mercury/lmmbhg.pdf

McGuire, L., V.J. Hoffman and S. Paulsen, 2009. Bay Area Petroleum Refinery Mercury Air Emissions, Deposition and Fate. Western States Petroleum Association (WSPA), project number 0032209. Online at: www.waterboards.ca.gov/rwqcb2/water_issues/programs/TMDLs/sfbaymercury/Hg_Air_Dep_SFB_Refineries%20_WSPA.pdf

Miles, C.J., H. Ansonmoye, E.J. Philips and B. Sargent, 2001. Partitioning of monomethylmercury between freshwater algae and water. Environmental Science and Technology, 35:4277-4282.

Milieu, 2010a. Environmental, Economic and Social Impacts of the Use of Sewage Sludge on Land. Part I: Overview Report. Report prepared for the European Commission under Study Contract DG ENV.G.4/ETU/2008/0076r.

Milieu, 2010b. Environmental, Economic and Social Impacts of the Use of Sewage Sludge on Land. Part II: Report on Options and Impacts. Report prepared for the European Commission under Study Contract DG ENV.G.4/ETU/2008/0076r.

Monperrus, M., E. Tessier, D. Amouroux, A. Leynaert, P. Huonnic and O.F.X. Donard, 2007. Mercury methylation, demethylation and reduction rates in coastal and marine surface waters of the Mediterranean Sea. Marine Chemistry, 107:49-63.

Monteiro, L.R. and R.W. Furness, 1997. Accelerated increase in mercury contamination in north Atlantic mesopelagic food chains as indicated by time series of seabird feathers. Environmental Toxicology and Chemistry, 16:2489-2493.

Montgomery, S., M. Lucotte and I. Rheault, 2000. Temporal and spatial influences of flooding on dissolved mercury in boreal reservoirs. Science of the Total Environment, 260:147-157.

Morel, F.M.M., A.M.L. Kraepiel and M. Amyot, 1998. The chemical cycle and bioaccumulation of mercury. Annual Reviews of Ecology and Systematics, 29:543-566.

Mosbæk, H., J. Tjell and T. Sevel, 1988. Plant uptake of airborne mercury in background areas. Chemosphere, 17:1227-1236.

Mukherjee, A. B., P. Bhattacharya, A. Sarkar, R. Zevenhoven, 2008. Mercury emissions from industrial sources in India and its effects in the environment. In: Pirrone, N. and R. Mason (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 81-112. Springer.

Munthe, J. and H. Hultberg, 2004. Mercury and methylmercury in runoff from a forested catchment – Concentrations, fluxes and their response to manipulations. Water, Air and Soil Pollution: Focus, 4:607-618.

Munthe, J., R.A. Bodaly, B.A. Branfireun, C.T. Driscoll, C.C. Gilmour, R. Harris, M. Horvat, M. Lucotte and O. Malm, 2007. Recovery of mercury-contaminated fisheries. Ambio, 36:33-44.

Murphy, D.M., D.S. Thomson and M.J. Mahoney, 1998. In situ measurements of organics, meteoritic material, mercury, and other elements in aerosols at 5 to 19 kilometers. Science, 282:1664-1669.

Murphy, D.M., P.K. Hudson, D.S. Thomson, P.J. Sheridan and J.C. Wilson, 2006. Observations of mercury-containing aerosols. Environmental Science and Technology, 40:3163-3167.

Myers, T., R.D. Atkinson, O.R. Bullock Jr., and J.O. Bash, 2012. Investigation of effects of varying model inputs on mercury deposition estimates in the Southwest US. Atmospheric Chemistry and Physics Discussions, 12:10273-10304.

NCPA, 2011. Information from Norway on releases of mercury from the oil and gas sector. Norwegian Climate and Pollution Agency. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/INC3/Norway_information.pdf

Neff, J.M., J.P. Ray, J.P. Smith and M.E. Parker, 2003. Environmental effects of mercury in permitted discharges from offshore platforms in the U.S. Gulf of Mexico. Workshop on Offshore Oil and Gas Environmental Effects Monitoring, Bedford Institute of Oceanography Dartmouth, Nova Scotia, May 26-30, 2003. Environmental Studies Research Funds Report No. 160.

Nelson, P.F., 2007. Atmospheric emissions of mercury from Australian point sources. Atmospheric Environment, 41:1717-1724.

Nelson, P.F., H. Nguyen, A.L. Morrison, H. Malfroy, M.E. Cope, M.F. Hibberd, S. Lee, J.L. McGregor and M. Meyer, 2009 (revised April 2011). Mercury Sources, Transportation and Fate in Australia - Final Report to the Department of Environment, Water, Heritage & the Arts. RFT 100/0607. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/A_Inventories/AUSTRALIA_Hg_inventory%20FINAL_REVISED_April%202011.pdf

NESCAUM ,2010. Measurement of mercury emissions from coal-fired power plants in the United States: A 2010 status report. Northeast States for Coordinated Air Use Management (NESCAUM).

NESHAP, 2010. Summary of Environmental and Cost Impacts of Final Amendments to Portland Cement NESHAP (40 CFR Part 63, subpart LLL). Docket Number EPA-HQ-OAR-2002-0051.

Nguyen, H., K.-H. Kim, M.-Y. Kim, S. Hong, Y.-H. Youn, Z.-H. Shon and J. Lee, 2007. Monitoring of atmospheric mercury at a global atmospheric watch (GAW) site on An-Myun Island, Korea. Water, Air and Soil Pollution, 185:149-164.

Nguyen, H.N., B.G. Martinsson, J.B. Wagner, E. Carlemalm, M. Ebert, S. Weinbruch, C.A. Brenninkmeijer, J. Heintzenberg, M. Hermann, T. Schuck, P.F.J. van Velthoven and A. Zahn, 2008. Chemical composition and morphology of individual aerosol particles from a CARIBIC flight at 10 km altitude between 50°N and 30°S. Journal of Geophysical Research, 113:D23209.

Nguyen, H.T., M.-Y. Kim and K.-H. Kim, 2010. The influence of long-range transport on atmospheric mercury on Jeju Island, Korea. Science of the Total Environment, 408:1295-1307.

Nguyen, D.L., J.Y. Kim, S.-G. Shim and X.-S. Zhang, 2011. Ground and shipboard measurements of atmospheric gaseous elemental mercury over the Yellow Sea region during 2007–2008. Atmospheric Environment, 45:253-260.

NPL, 2012. Kaye and Laby: Tables of Physical and Chemical Constants. National Physical Laboratory (NPL). Online at: www.kayelaby.npl.co.uk

Nriagu, J.O., 1994. Mercury pollution from the past mining of gold and silver in the Americas. Science of the Total Environment, 149:167-181.

Nriagu, J. and C. Becker, 2003. Volcanic emissions of mercury to the atmosphere: global and regional inventories. Science of the Total Environment, 304:3-12.

Nriagu, J.O., H.K.T. Wong, G. Lawson and P. Daniel, 1998. Saturation of ecosystems with toxic metals in Sudbury basin, Ontario, Canada. Science of the Total Environment, 223:99-117.

Obrist, D., A.G. Hallar, I. McCubbin, B.B. Stephens and T. Rahn, 2008. Atmospheric mercury concentrations at Storm Peak Laboratory in the Rocky Mountains: Evidence for long-range transport from Asia, boundary layer contributions, and plant mercury uptake. Atmospheric Environment, 42:7579-7589.

Obrist, D., E. Tas, M. Peleg, V. Matveev, X. Faïn, D. Asaf and M. Luria, 2011. Bromine-induced oxidation of mercury in the mid-latitude atmosphere. Nature Geoscience, 4:22-26.

OGJ, 2006. Oil & Gas Journal 2006 Worldwide Refining Survey. Online at: http://bbs.keyhole.com/ubb/showthreaded.php/Cat/0/Number/1197575/page/

Ogrinc, N., M. Monperrus, J. Kotnik, et al., 2007. Distribution of mercury and methylmercury in deep-sea surficial sediments of the Mediterranean Sea. Marine Chemistry, 107:31-48.

Oram, D.E., F.S. Mani, J.C. Laube, M.J. Newland, C.E. Reeves, W.T. Sturges, S.A. Penkett, C.A.M. Brenninkmeijer, T. Rockmann and P.J. Fraser, 2012. Long-term tropospheric trend of octafluorocyclobutane c-C4F8 or PFC-318. Atmospheric Chemistry and Physics, 12:261-269.

Orihel, D.M., M.J. Paterson, C.C. Gilmour, R.A. Bodaly, P.J. Blanchfield, H. Hintelmann, R.C. Harris and J.W.M. Rudd, 2006. Effect of loading rate on the fate of mercury in littoral mesocosms. Environmental Science and Technology, 40:5992-6000.

Osawa, T., T. Ueno and F. Fu, 2007. Sequential variation of atmospheric mercury in Tokai-mura, seaside area of eastern central Japan. Journal of Geophysical Research,112:D19107.

OSPAR, 2005. Assessment of data collected under the OSPAR Comprehensive Study on Riverine Inputs and Direct Discharges for the period 1990 – 2002. OSPAR Commission, London.

OSPAR, 2011. Mercury losses from the chlor-alkali industry in 2009, including an assessment of 2008 and 2009 data and trends. OSPAR Commission, London.

Outridge, P.M., 2005. Using biological archives to discriminate natural and anthropogenic mercury in animals: a methodological review. In: Parsons, M.B. and J.B. Percival (Eds.). Mercury – Sources, Measurements, Cycles and Effects, pp. 217-234. Mineralogical Association of Canada Short Course Halifax, Novia Scotia.

Outridge, P.M., R. Wagemann and R. McNeely, 2000. Teeth as biomonitors of soft tissue mercury concentrations in beluga, *Delphinapterus leucas*. Environmental Toxicology and Chemistry, 19:1517-1522.

Outridge, P.M., K.A. Hobson, R. McNeely and A. Dyke, 2002. A comparison of modern and preindustrial levels of mercury in the teeth of beluga in the Mackenzie Delta, Northwest Territories, and walrus at Igloolik, Nunavut, Canada. Arctic, 55:123-132.

Outridge, P.M., K.A. Hobson and J.M. Savelle, 2005. Changes in mercury and cadmium concentrations and the feeding behaviour of beluga (*Delphinapterus leucas*) near Somerset Island, Canada, during the 20th century. Science of the Total Environment, 350:106-118.

Outridge, P.M., R.W. Macdonald, F. Wang, G.A. Stern and A. Dastoor, 2008. A mass balance inventory of mercury in the Arctic Ocean. Environmental Chemistry, 5:89-111.

Outridge, P.M., K.A. Hobson and J. Savelle, 2009. Long-term changes of mercury levels in ringed seal (*Phoca hispida*) from Amundsen Gulf, and beluga (*Delphinapterus leucas*) from the Beaufort Sea, western Canadian Arctic. Science of the Total Environment, 407:6044-6051.

Outridge, P.M., N. Rausch, J.B. Percival, W. Shotyk and R. McNeely, 2011. Comparison of mercury and zinc profiles in peat and lake sediment archives with historical changes in emissions from the Flin Flon metal smelter, Manitoba, Canada. Science of the Total Environment, 409:548-563.

Pacyna, E.G. and J.M. Pacyna, 2002. Global emission of mercury from anthropogenic sources in 1995. Water, Air and Soil Pollution, 137: 149-165.

Pacyna, J.M. and E.G. Pacyna, 2005. Anthropogenic sources and global inventory of mercury emissions. In: Parsons, M.B. and J.B. Percival (Eds.), Mercury: Sources, Measurements, Cycles, and Effects. Mineralogical Association of Canada, Short Course Series Volume No. 32.

Pacyna, J.M., E.G. Pacyna, F. Steenhuisen and S. Wilson, 2003. Mapping 1995 global anthropogenic emissions of mercury. Atmospheric Environment, 37-S:109-117.

Pacyna, E.G., J.M. Pacyna, F. Steenhuisen and S. Wilson, 2006. Global anthropogenic mercury emission inventory for 2000. Atmospheric Environment, 40:4048-4063.

Pacyna, E.G., J.M. Pacyna, K. Sundseth, J. Munthe, K. Kindbom, S. Wilson, F. Steenhuisen and P. Maxson, 2009. Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. Atmospheric Environment, 44:2487-2499.

Pal, B. and P.A. Ariya, 2004. Gas-phase HO•-initiated reactions of elemental mercury: kinetics, product studies, and atmospheric implications. Environmental Science and Technology, 38:5555-5566.

Pan, L., J.-H. Woo, G.R. Carmichael, Y. Tang, H.R. Friedli and L.F. Radke, 2006. Regional distribution and emissions of mercury in East Asia: A modeling analysis of Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia) observations. Journal of Geophysical Research, 111:D07109.

Pan, L., T.F. Chai, G.R. Carmichael, Y.H. Tang, D. Streets, J.H. Woo, H.R. Friedli and L.F. Radke, 2007. Top-down estimate of mercury emissions in China using four-dimensional variational data assimilation. Atmospheric Environment, 41:2804-2819.

Pan, L., G.R. Carmichael, B. Adhikary, Y. Tang, D. Streets, J.-H. Woo, H.R. Friedli and L.F. Radke, 2008. A regional analysis of the fate and transport of mercury in East Asia and an assessment of major uncertainties. Atmospheric Environment, 42:1144-1159.

Pan, L., C.-J. Lin, G.R. Carmichael, D.G. Streets, Y. Tang, J.-H. Woo, S.K. Shetty, H.-W. Chu, T.C. Ho, H.R. Friedli and X. Feng, 2010. Study of atmospheric mercury budget in East Asia using STEM-Hg modeling system. Science of the Total Environment, 408:3277-3291.

Parsons, M.B., G.E.M. Hall, J. Dalziel, R. Tordon, S. Winch, K.G. Doe, R. Mroz and V.P. Palace, 2011. Environmental impacts of historical mercury amalgamation at gold mines in Nova Scotia, Canada. The 10th International Conference on Mercury as a Pollutant. Halifax, Nova Scotia, Canada. 25 July 2011.

Paterson, M.J., J.W.M. Rudd and V. St. Louis, 1998. Increases in total and methylmercury in zooplankton following flooding of a peatland reservoir. Environmental Science and Technology, 32:3868-3874.

Pavlish, J.H., L.L. Hamre and Y. Zhuang, 2010. Mercury control technologies for coal combustion and gasification systems. Fuel, 89:838-847.

PCA, 2008. Sustainable manufacturing fact sheet: Tire-derived fuel. May 2008. Portland Cement Association. http://www.cement.org/Briefingkit/pdf_files/TDFBrochure.pdf

Pfeiffer, W.C., L.D. Lacerda, W. Salomons and O. Malm, 1993. Environmental fate of mercury from gold mining in the Brazilian Amazon. Environmental Reviews, 1:26-37.

Pirrone, N. and T. Keating, 2010. Hemispheric Transport of Air Pollution 2010. Part B: Mercury. Air Pollution Studies No. 16. United Nations.

Pirrone, N. and R. Mason, 2009. Mercury Fate and Transport in the Global Atmosphere: Emissions, Measurements and Models. Springer, 637 pp.

Pirrone, N., R. Ferrara, I.M. Hedgecock, G. Kallos, Y. Mamane, J. Munthe, J.M. Pacyna, I. Pytharoulis, F. Sprovieri, A. Voudouri and I. Wängberg, 2003. Dynamic processes of mercury over the Mediterranean region: results from the Mediterranean Atmospheric Mercury Cycle System (MAMCS) project. Atmospheric Environment, 37(Supplement 1):S21-S39.

Pirrone, N., I.M. Hedgecock and F. Sprovieri, 2008. New directions: atmospheric mercury, easy to spot and hard to pin down: impasse? Atmospheric Environment, 42:8549-8551.

Pirrone, N., S. Cinnirella, X. Feng, R.B. Finkelman, H.R. Friedli, J. Leaner, R. Mason, A.B. Mukherjee, G.B. Stracher, D.G. Streets and K. Telmer, 2010. Global mercury emissions to the atmosphere from anthropogenic and natural sources. Atmospheric Chemistry and Physics, 10:5951-5964.

Poissant, L., M. Pilote, X. Xu, H. Zhang and C. Beauvais, 2004. Atmospheric mercury speciation and deposition in the Bay St. François wetlands. Journal of Geophysical Research,109:D11301.

Poissant, L., M. Pilote, C. Beauvais, P. Constant and H.H. Zhang, 2005. A year of continuous measurements of three atmospheric mercury species (GEM, RGM and Hgp) in southern Québec, Canada. Atmospheric Environment, 39:1275-1287.

Ponge, B., 2012. ISA environmental management, and potential interactions with OSPAR High Seas Marine Protected Areas. Document prepared by the French Marine Protected Areas Agency for submission to the OSPAR Madeira II workshop, January 2012, Paris.

Pongprueksa, P., C.-L. Lin, S.E. Lindberg, C. Jang, T. Braverman, O.R.B. Jr., T.C. Ho and H.-W. Chu, 2008. Scientific uncertainties in atmospheric mercury models III: Boundary and initial conditions, model grid resolution, and Hg(II) reduction mechanism. Atmospheric Environment, 42:1828-1845.

Prestbo, E.M. and D.A. Gay, 2009. Wet deposition of mercury in the U.S. and Canada, 1996–2005: Results and analysis of the NADP mercury deposition network (MDN). Atmospheric Environment, 43:4223-4233.

Prestbo, E.M., D. Gay, D. Schmeltz, P. Blanchard, R. Tordon, M. Olson, T. Sharac and T. Bergerhouse, 2011. North American atmospheric mercury speciation networks: using high quality data for multipurpose analysis. Presented at the 10th International Conference on Mercury as a Global Pollutant, July 24-29, 2011, Halifax, Nova Scotia, Canada. Online at: www.mercury2011.org

Pudasainee, D., J.-H. Kim, S.-H. Lee, S.-J. Cho, G.-J. Song and Y.-C. Seo, 2009a. Hazardous air pollutants emission characteristics from cement kilns co-burning wastes. Environmental Engineering Research, 14:212-219.

Pudasainee, D., J.-H. Kim and Y.-C. Seo, 2009b. Mercury emission trend influenced by stringent air pollutants regulation for coal-fired power plants in Korea. Atmospheric Environment, 43:6254-6259.

Pudasainee, D., S.J. Lee, S.-H. Lee, J.-H. Kim, H.-N. Jang, S.-J. Cho and Y.-C. Seo, 2010. Effect of selective catalytic reactor on oxidation and enhanced removal of mercury in coal-fired power plants. Fuel, 89:804-809.

Pudasainee, D., J.-H. Kim, Y.-S. Yoon and Y.-C. Seo, 2012. Oxidation, reemission and mass distribution of mercury in bituminous coal-fired power plants with SCR, CS-ESP and wet FGD. Fuel, 93:312-318.

Pyle, D.M. and T.A. Mather, 2003. The importance of volcanic emissions for the global atmospheric mercury cycle. Atmospheric Environment, 37:5115-5124.

Qureshi, A., M. MacLeod, M. Scheringer and K. Hungerbühler, 2009. Mercury cycling and species mass balances in four North American lakes. Environmental Pollution, 157:452-462.

Qureshi, A., M. MacLeod and K. Hungerbühler, 2011. Quantifying uncertainties in the global mass balance of mercury. Global Biogeochemical Cycles, 25:GB4012.

Rajar, R., D. Žagar, M. Četina, H. Akagi, S. Yano, T. Tomiyasu and M. Horvat, 2004. Application of three-dimensional mercury cycling model to coastal seas. Ecological Modelling, 171:139-155.

Rajar, R., M. Četina, M. Horvat and D. Žagar, 2007. Mass balance of mercury in the Mediterranean Sea. Marine Chemistry, 107:89-102.

Rea, A.W., S.E. Lindberg, T. Scherbatskoy and G.J. Keeler, 2002. Mercury accumulation in foliage over time in two northern mixed-hardwood forests. Water, Air and Soil Pollution, 133:49-67.

Remy, S., P. Prudent, C. Hissler, J.L. Probst and G. Krempp, 2003. Total mercury concentrations in an industrialized catchment, the Thur River basin (north-eastern France): geochemical background level and contamination factors. Chemosphere, 52:635-644.

Rigét, F., B. Braune, A. Bignert, S. Wilson, J. Aars, E. Born, M. Dam, R. Dietz, M. Evans, T. Evans, M. Gamberg, N. Gantner, N. Green, H. Gunnlaugdóttir, K. Kannan, R. Letcher, D. Muir, P. Roach, C. Sonne, G. Stern and Ø. Wiig, 2011. Temporal trends of Hg in Arctic biota, an update. Science of the Total Environment, 409:3520-3526.

Riscassi, A.L., K.J. Hokanson and T.M. Scanlon, 2011. Streamwater particulate mercury and suspended sediment dynamics in a forested headwater catchment. Water, Air and Soil Pollution, 220:23-36.

Risch, M.R., D.A. Gay, K.K. Fowler, G.J. Keeler, S.M. Backus, P. Blanchard, J.A. Barres and J.T. Dvonch, 2012. Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002–2008. Environmental Pollution, 161:261-271.

Roulet, M., M. Lucotte, N. Farella, G. Serique, H. Coelho, C.J. Sousa Passos, E.D.J. DaSilva, P. Scavone de Andrade, D. Mergler, J.-R.D. Guimarães and M. Amorim, 1999. Effects of recent human colonization on the presence of mercury in Amazonian ecosystems. Water Air and Soil Pollution, 112:297-313.

Roulet, M., M. Lucotte, R. Canuel, N. Farella, Y.G. De Freitos Goch, J.R. Pacheco Peleja, J.-R.D. Guimarães, D. Mergler and M. Amori, 2001. Spatio-temporal geochemistry of mercury in waters of the Tapajós and Amazon rivers, Brazil. Limnology and Oceanography, 46:1141-1157.

Roustan, Y. and M. Bocquet, 2006. Sensitivity analysis for mercury over Europe. Journal of Geophysical Research, 111:D14304.

Ryaboshapko, A., O.R. Bullock Jr., J. Christensen, M. Cohen, A. Dastoor, I. Ilyin, G. Petersen, D. Syrakov, R.S. Artz, D. Davignon, R.R. Draxler and J. Munthe, 2007a. Intercomparison study of atmospheric mercury models: 1. Comparison of models with short-term measurements. Science of the Total Environment, 376:228-240.

Ryaboshapko, A., O.R. Bullock Jr., J. Christensen, M. Cohen, A. Dastoor, I. Ilyin, G. Petersen, D. Syrakov, O. Travnikov, R.S. Artz, D. Davignon, R.R. Draxler, J. Munthe and J. Pacyna, 2007b. Intercomparison study of atmospheric mercury models: 2. Modelling results vs. long-term observations and comparison of country deposition budgets. Science of the Total Environment, 377:319-333.

Ryall, D. and R. Maryon, 1998. Validation of the UK Met. Office's name model against the ETEX dataset. Atmospheric Environment, 32:4265-4276.

Ryall, D., R. Maryon, R. Derwent and P. Simmonds, 1998. Modelling long-range transport of CFCs to Mace Head, Ireland. Quarterly Journal of the Royal Meteorological Society, 124:417-446.

Rydberg, J., J. Klaminder, P. Rosen and R. Bindler, 2010. Climate driven release of carbon and mercury from permafrost mires increases mercury loading to sub-arctic lakes. Science of the Total Environment, 408:4778-4783.

Rytuba, J.J., 2003. Mercury from mineral deposits and potential environmental impact. Environmental Geology, 43:326-338.

Sakata, M. and K. Marumoto, 2005. Wet and dry deposition fluxes of mercury in Japan. Atmospheric Environment, 39:3139-3146.

Sarica, J., M. Amyot, L. Hare, M.R. Doyon and L.W. Stanfield, 2004. Salmon-derived mercury and nutrients in a lake Ontario spawning stream. Limnology and Oceanography, 49:891-899.

Schafer, J., G. Blanc, S. Audry, D. Cossa and C. Bossy, 2006. Mercury in the Lot-Garonne River system (France): Sources, fluxes and anthropogenic component. Applied Geochemistry, 21:515-527.

Scheuhammer, A.M., 1987. The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: a review. Environmental Pollution, 46:263-295.

Schlüter, K., 1993. The fate of mercury in soil. A review of current knowledge. Technical report, Commission of the European Communities.

Schroeder, W.H., G. Keeler, H. Kock, P. Roussel, D. Schneeberger and F. Schaedlich, 1995. International field intercomparison of atmospheric mercury measurement methods. Water, Air and Soil Pollution, 80:611-620.

Schroeder, W.H., K.G. Anlauf, L.A. Barrie, J.Y. Lu, A. Steffen, D.R. Schneeberger and T. Berg, 1998. Arctic springtime depletion of mercury. Nature, 394:331-332.

Schuck, T.J., C.A.M. Brenninkmeijer, F. Slemr, I. Xueref-Remy and A. Zahn, 2009. Greenhouse gas analysis of air samples collected onboard the CARIBIC passenger aircraft. Atmospheric Measurement Techniques, 2:449-464.

Schuster, E., 1991. The behavior of mercury in the soil with special emphasis on complexation and adsorption processes - A review of the literature. Water, Air and Soil Pollution, 56:667-680.

Schuster, P.F., D.P. Krabbenhoft, D.L. Naftz, L.D. Cecil, M.L. Olson, J.F. Dewild, D.D. Susong, J.R. Green and M.L. Abbott, 2002. Atmospheric mercury deposition during the last 270 years: A glacial ice core record of natural and anthropogenic sources. Environmental Science and Technology, 36:2303-2310.

Schuster, P.F., R.G. Striegl, G.R. Aiken, D.P. Krabbenhoft, J.F. Dewild, K. Butler, B. Kamark and M. Dornblaser, 2011. Mercury export from the Yukon River Basin and potential response to a changing climate. Environmental Science and Technology, 245:9262-9267.

Scudder, B.C., L.C. Chasar, D.A. Wentz, N.J. Bauch, M.E. Brigham, P.W. Moran and D.P. Krabbenhoft, 2009. Mercury in fish, bed sediment, and water from streams across the United States, 1998–2005. U.S. Geological Survey Scientific Investigations Report 2009–5109, 74p.

Seigneur, C., K. Vijayaraghavan, K. Lohman, P. Karamchandani and C. Scott, 2004. Global source attribution for mercury deposition in the United States. Environmental Science and Technology, 38:555-569.

Seinfeld, J.H. and S.N. Pandis, 1998. Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. J. Wiley.

Selin, N.E., 2009. Global biogeochemical cycling of mercury: A review. Annual Review of Environment and Resources, 34:43-63.

Selin, N.E. and D.J. Jacob, 2008. Seasonal and spatial patterns of mercury wet deposition in the United States: Constraints on the contribution from North American anthropogenic sources. Atmospheric Environment, 42:5193-5204.

Selin, N.E., D.J. Jacob, R., Park, R.M. Yantosca, S.A. Strode, L. Jaeglé and D. Jaffe, 2007. Chemical cycling and deposition of atmospheric mercury: Global constraints from observations. Journal of Geophysical Research, 112:D02308.

Selin, N.E., D.J. Jacob, R. Yantosca, S.A. Strode, L. Jaeglé and E.M. Sunderland, 2008. Global 3-D land-ocean–atmosphere model for mercury: Present-day versus preindustrial cycles and anthropogenic enrichment factors for deposition. Global Biogeochemical Cycles, 22:GB2011.

Selin, N.E., E.M. Sunderland, C.D. Knightes and R.P. Mason, 2010. Sources of mercury exposure for US seafood consumers: implications for policy. Environmental Health Perspectives, 118:137-143.

Sellers, P., C.A. Kelly, J.W.M. Rudd and A.R. MacHutchon, 1996. Photodegradation of methylmercury in lakes. Nature, 380:694-697.

SEMARNAT, 2010. Mexican Pollutant Release and Transfer Register. Mexico Ministry of Environment and Natural Resources / - Registro de Emisiones y Transferencia de Contaminantes (RETC). Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). Online at: http://app1.semarnat.gob.mx/retc/retc/index.php

Seo, Y.-S., Y.-J. Han, H.-D. Choi, T.M. Holsen and S.-M. Yi, 2012. Characteristics of total mercury (TM) wet deposition: Scavenging of atmospheric mercury species. Atmospheric Environment, 49:69-76.

Shanley, J.B. and K. Bishop, 2012. Mercury cycling in terrestrial watersheds. In. Bank M.S. (Ed.) Mercury in the Environment: Pattern and Process, pp. 119-142. University of California Press, 340 p.

Shanley, J.B., N.C. Kamman, T.A. Clair and A. Chalmers, 2005. Physical controls on total and methylmercury concentrations in streams and lakes of the Northeastern USA. Ecotoxicology, 14:125-134.

Sharac, T., D. Gay, D. Schmeltz, M. Olson, E. Prestbo, T. Bergerhouse, M. Cohen, W. Luke and P. Kelley, 2011. The North American Atmospheric Mercury Speciation Network. Tenth International Conference on Mercury as a Global Pollutant (ICMGP 2011), 24-29 July, 2011, Halifax, Nova Scotia, Canada. Online at: www.mercury2011.org

Sherman, L.S. and J.D. Blum, 2012. Mercury stable isotopes in sediments and large-mouth bass from Florida lakes, USA. Science of the Total Environment, doi: 10.1016/j.scitotenv2012.09.038.

Sherman, L.S., J.D. Blum, G.J. Keeler, J.D. Demers and J.T. Dvonch, 2012. Investigation of local mercury deposition from a coal-fired power plant using mercury isotopes. Environmental Science and Technology, 46:382-390.

Sheu, G.-R., N.-H. Lin, J.-L. Wang, C.-T. Lee, C.-F. Yang and S.-H. Wang, 2010. Temporal distribution and potential sources of atmospheric mercury measured at a high-elevation background station in Taiwan. Atmospheric Environment, 44:2393-2400.

Shia, R.-L., C. Seigneur, P. Pai, M. Ko and N.D. Sze, 1999. Global simulation of atmospheric mercury concentrations and deposition fluxes. Journal of Geophysical Research, 104:23747-23760.

Sillman, S., F.J. Marsik, K.I. Al-Wali, G.J. Keeler and M.S. Landis, 2007. Reactive mercury in the troposphere: Model formation and results for Florida, the northeastern United States, and the Atlantic Ocean. Journal of Geophysical Research, 112:D23305.

Simpson, W.R., R. von Glasow, K. Riedel, P. Anderson, P. Ariya, J. Bottenheim, J. Burrows, L.J. Carpenter, U. Frieß, M.E. Goodsite, D. Heard, M. Hutterli, H.-W. Jacobi, L. Kaleschke, B. Neff, J. Plane, U. Platt, A. Richter, H. Roscoe, R. Sander, P. Shepson, J. Sodeau, A. Steffen, T. Wagner and E. Wolff, 2007. Halogens and their role in polar boundary layer ozone depletion. Atmospheric Chemistry and Physics, 7:4375-4418.

Skov, H., J.H. Christensen, M.E. Goodsite, N.Z. Heidam, B. Jensen, P. Wåhlin and G. Geernaert, 2004. Fate of elemental mercury in the Arctic during atmospheric mercury depletion episodes and the load of atmospheric mercury to the Arctic. Environmental Science and Technology, 38:2373-2382.

Slemr, F., E.-G. Brunke, C. Labuschagne and R. Ebinghaus, 2008. Total gaseous mercury concentrations at the Cape Point GAW station and their seasonality. Geophysical Research Letters, 35:L11807.

Slemr, F., R. Ebinghaus, C.A.M. Brenninkmeijer, M. Hermann, H.H. Kock, B.G. Martinsson, T. Schuck, D. Sprung, P. van Velthoven, A. Zahn and H. Ziereis, 2009. Gaseous mercury distribution in the upper troposphere and lower stratosphere observed onboard the CARIBIC passenger aircraft. Atmospheric Chemistry and Physics, 9:1957-1969.

Slemr, F., E.-G. Brunke, R. Ebinghaus and J. Kuss, 2011. Worldwide trend of atmospheric mercury since 1995. Atmospheric Chemistry and Physics, 11:4779-4787.

Slemr, F., R. Ebinghaus, A. Weigelt, H.H. Kock, C.A.M. Brenninkmeijer, T. Schuck, M. Hermann, A. Zahn, P. van Velthoven, B. Martinsson and H. Ziereis, 2012. CARIBIC observations of gaseous mercury in the upper troposphere and lower stratosphere. Proceedings of the 16th International Conference on Heavy Metals in the Environment (ICHMET 2012), Rome, Italy, 23-27 September 2012.

Sloss, L.L., 2008. Economics of Mercury Control. CCC/134, IEA Clean Coal Center. 60 pp. Online at: http://bookshop.iea-coal.org/report/80572/Environmental-policy-and-legislation/82021/Economics-of-mercury-control,-CCC-134

Smart, N.A., 1968. Use and residues of mercury compounds in agriculture. Residue Reviews, 23:1.

Smith-Downey, N.V., E.M. Sunderland and D.J. Jacob, 2010. Anthropogenic impacts on global storage and emissions of mercury from terrestrial soils: Insights from a new global model. Journal of Geophysical Research, 115:G03008.

Sørensen, R., M. Meili, L. Lambertsson, C. Brömssen and K. Bishop, 2009. The effects of forest harvest operations on mercury and methylmercury in two boreal streams: relatively small changes in the first two years prior to site preparation. Ambio, 38:364-372.

Soerensen, A., E. Sunderland, C. Holmes, D. Jacob, R. Yantosca, H. Skov, J. Christensen, S. Strode and R. Mason, 2010. An improved global model for air-sea exchange of mercury: High concentrations over the North Atlantic. Environmental Science and Technology, 44:8574-8580.

Soerensen, A.L, D.J. Jacob, D.G. Streets, M.L.I. Witt, R. Ebinghaus, R.P. Mason, M. Andersson and E.M. Sunderland, 2012, Multi-decadal decline of mercury in the North Atlantic atmosphere explained by changing subsurface seawater concentrations. Geophysical Research Letters, 39:L21810.

Sommar, J., I. Wängberg, T. Berg, K. Gårdfeldt, J. Munthe, A. Richter, A. Urba, F. Wittrock and W.H. Schroeder, 2007. Circumpolar transport and air-surface exchange of atmospheric mercury at Ny-Alesund (79° N), Svalbard, spring 2002. Atmospheric Chemistry and Physics, 7:151-166.

Sonke, J.E., 2011. A global model of mass independent mercury stable isotope fractionation. Geochimica et Cosmochimica Acta, 75:4577-4590.

Sprovieri, F., N. Pirrone, M. Landis and R. Stevens, 2005. Atmospheric mercury behavior at different altitudes at Ny Alesund during Spring 2003. Atmospheric Environment, 39:7646-7656.

Sprovieri, F., I.M. Hedgecock and N. Pirrone, 2010. An investigation of the origins of reactive gaseous mercury in the Mediterranean marine boundary layer. Atmospheric Chemistry and Physics, 10:3985-3997.

Sprovieri, F., L.E. Gratz and N. Pirrone, 2012. Development of a ground-based atmospheric monitoring network for the Global Mercury Observation System (GMOS). Proceedings of the 16th International Conference on Heavy Metals in the Environment (ICHMET 2012), Rome, Italy, 23-27 September 2012.

Srivastava, R.K, N. Hutson, B. Martin and F. Princiotta, 2006. Control of mercury emissions from coal-fired electricity utility boilers. Environmental Science and Technology, 40:1385-1393.

St. Louis, V., H. Hintelmann, J.A. Graydon, J.L. Kirk, J. Barker, B. Dimock, M.J. Sharp and I. Lehnherr, 2007. Methylated mercury species in Canadian High Arctic marine surface waters and snowpacks. Environmental Science and Technology, 241:6433-6441.

Statistics Korea, 2010. Domestic Demand and Supply of Nonferrous Metals. Online at: kostat.go.kr

Steffen, A., W.H. Schroeder, R. Macdonald, L. Poissant and A. Konoplev, 2005. Mercury in the arctic atmosphere: an analysis of eight years of measurements of GEM at Alert (Canada) and a comparison with observations at Amderma (Russia) and Kuujjuarapik (Canada). Science of the Total Environment, 342:185-198.

Steffen, A., T. Douglas, M. Amyot, P. Ariya, K. Aspmo, T. Berg, J. Bottenheim, S. Brooks, F. Cobbett, A. Dastoor, A. Dommergue, R. Ebinghaus, C. Ferrari, K. Gardfeldt, M.E. Goodsite, D. Lean, A.J. Poulain, C. Scherz, H. Skov, J. Sommar and C. Temme, 2008. A synthesis of atmospheric mercury depletion event chemistry in the atmosphere and snow. Atmospheric Chemistry and Physics, 8:1445-1482.

Steffen, A., T. Scherz, M. Olson, D. Gay and P. Blanchard, 2012. A comparison of data quality control protocols for atmospheric mercury speciation measurements. Journal of Environmental Monitoring, 14:752-765.

Steinnes, E., 1997. Mercury. In: Alloway, B.J. (Ed.). Heavy Metals in Soils, pp. 245-259. Blackie Academic & Professional.

Stern, G.A., R.W. Macdonald, P.M. Outridge, S. Wilson, J. Chetelat, A. Cole, H. Hintelmann, L.L. Loseto, A. Steffen, F. Wang and C. Zdanowicz, 2012. How does climate change influence arctic mercury? Science of the Total Environment, 414:22-42.

Streets, D.G., J. Hao, Y. Wu, J. Jiang, M. Chan, H. Tian and X. Feng, 2005. Anthropogenic mercury emissions in China. Atmospheric Environment, 39:7789-7806.

Streets, D.G., Q. Zhang and Y. Wu, 2009. Projections of global mercury emissions in 2050. Environmental Science and Technology, 43:2983-2988.

Streets, D.G., M.K. Devane, Z. Lu, T.C. Bond, E.M. Sunderland and D.J. Jacob, 2011. All-time releases of mercury to the atmosphere from human activities. Environmental Science and Technology, 45:10485-10491.

Strode, S., L. Jaegle, N. Selin, D. Jacob, R. Park, R. Yantosca, R. Mason and F. Slemr, 2007. Air-sea exchange in the global mercury cycle. Global Biogeochemical Cycles, 21:GB1017.

Strode, S.A., L. Jaeglé, D.A. Jaffe, P.C. Swartzendruber, N.E. Selin, C. Holmes and R.M. Yantosca, 2008. Trans-Pacific transport of mercury. Journal of Geophysical Research, 113:D15305.

Strode, S., L. Jaeglé and S. Emerson, 2010. Vertical transport of anthropogenic mercury in the ocean**.** Global Biogeochemical Cycles, 24:GB4014.

Subir, M., P.A. Ariya and A.P. Dastoor, 2011. A review of uncertainties in atmospheric modeling of mercury chemistry I. Uncertainties in existing kinetic parameters – Fundamental limitations and the importance of heterogeneous chemistry. Atmospheric Environment, 45:5664-5676.

Subir, M., P.A. Ariya and A.P. Dastoor, 2012. A review of the sources of uncertainties in atmospheric mercury modeling II. Mercury surface and heterogeneous chemistry – A missing link. Atmospheric Environment, 46:1-10.

Suchanek, T.H., C.A. Eagles-Smith and E.J. Harner, 2008. Is Clear Lake methylmercury distribution decoupled from bulk mercury loading? Ecological Applications, 18:A107-A127.

Sun, L., X. Yin, X. Liu, R. Zhu, Z. Xie and Y. Wang, 2006. A 2000-year record of mercury and ancient civilizations in seal hairs from King George Island, West Antarctica. Science of the Total Environment, 368:236-247.

Sunderland, E.M., 2007. Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. Environmental Health Perspectives, 115:235-242.

Sunderland, E.M. and R.P. Mason, 2007. Human impacts on open ocean mercury concentrations. Global Biogeochemical Cycles, 21:GB4022.

Sunderland, E.M., D.P. Krabbenhoft, J.W. Moreau, S.A. Strode and W.M. Landing, 2009. Mercury sources, distribution, and bioavailability in the North Pacific Ocean: insights from data and models. Global Biogeochemical Cycles, 23:GB2010.

Sunderland, E.M., J. Dalziel, A. Heyes, B.A. Branfireun, D.P. Krabbenhoft and F. Gobas, 2010. Response of a macrotidal estuary to changes in anthropogenic mercury loading between 1850 and 2000. Environmental Science and Technology, 44:1698-1704.

Sunderland, E.M., D.P. Krabbenhoft, E.S. Corbitt and W.M. Landing, 2011. Distributions of mercury and methylmercury in the Indian Ocean. Presentation at the 10th International Conference on Mercury as a Global Pollutant, Halifax, Canada, 2011.

Sunderland, E.M., A. Amirbahman, N. Burgess, J. Dalziel, G. Harding, M.R. Karagas, S.H. Jones, X. Shi and C.Y. Chen, 2012. Mercury sources and fate in the Gulf of Maine. Environmental Research, 119:27-41.

Suzuki, N., Y. Shibara and K. Ogasawara, 2009. Monitoring and modeling the fate of Hg species in Japan. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 381-390. Springer.

Swartzendruber, P.C., D.A. Jaffe, E.M. Prestbo, P. Weiss-Penzias, N.E. Selin, R. Park, D.J. Jacob, S. Strode and L. Jaeglè, 2006. Observations of reactive gaseous mercury in the free troposphere at the Mount Bachelor Observatory. Journal of Geophysical Research, 111:D24301.

Swartzendruber, P.C., D.A. Jaffe and B. Finley, 2009. Development and first results of an aircraft-based, high time resolution technique for gaseous elemental and reactive (oxidized) gaseous mercury. Environmental Science and Technology, 43:7484-7489.

SYKE, 2012. Air Pollutant Emissions in Finland 1980–2010: Informative Inventory Report to the Secretariat of the UNECE Convention on Long-Range Transboundary Air Pollution. 30th March 2012 (revised). Finnish Environmental Institute.

Talbot, R., H. Mao, E. Scheuer, J. Dibb, M. Avery, E. Browell and others, 2008. Factors influencing the large-scale distribution of Hg degrees in the Mexico City area and over the North Pacific. Atmospheric Chemistry and Physics, 8:2103-2114.

Tang, S., X. Feng, J. Qiu, G. Yin and Z. Yang, 2007. Mercury speciation and emissions from coal combustion in Guiyang, southwest China. Environmental Research, 105:175-182.

Tang, R.W.K., T.A. Johnston, J.M. Gunn and S.P. Bhavsar 2013. Temporal changes in mercury concentrations of large-bodied fishes in the boreal shield ecoregion of northern Ontario, Canada. Science of the Total Environment, 444:409-416.

Telmer, K. and M. Veiga, 2009. World emissions of mercury from artisanal and small scale gold mining. In: Pirrone, N. and R. Mason (Eds.). Mercury Fate and Transport in the Global Atmosphere: Emissions, Measurements and Models, pp. 131-172. Springer.

Telmer, K., M. Costa, R.S. Angélica, E.S. Araujo and Y. Maurice, 2006. The source and fate of sediment and mercury in the Tapajós River, Pará, Brazilian Amazon: Ground- and space-based evidence. Journal of Environmental Management, 81:101-113.

Temme, C., P. Blanchard, A. Steffen, C. Banic, S. Beauchamp, L. Poissant, R. Tordon and B. Wiens, 2007. Trend, seasonal and multivariate analysis study of total gaseous mercury data from the Canadian atmospheric mercury measurement network (CAMNet). Atmospheric Environment, 41:5423-5441.

Theloke, J., U. Kummer, S. Nitter, T. Geftler, R. Friedrich, H. Denier van der Gon, A. Visschedijk, 2008. Überarbeitung der Schwermetallkapitel in CORINAIR Guidebook zur verbesserung der Emissionsinventare und der Berichterstattung im Rahmen der Genfer Luftreinhaltekonvention. Umwelt Bundes Amt.

Thérien, N. and K. Morrison, 1999. Calculated fluxes of mercury to fish in the Robert-Bourassa Reservoir. In: Lucotte, M., R. Schetagne, N. Thérien, C. Langlois and A. Tremblay (Eds.). Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Quebec, pp. 259-272. Springer.

Timonen, H., J.L. Ambrose and D.A. Jaffe, 2012. Two new sources of reactive gaseous mercury in the free troposphere. Atmospheric Chemistry and Physics Discussions, 12:29203-29233.

Tomiyasu, T., A. Matsuyama, T. Eguchi, Y. Fuchigami, K. Oki, M. Horvat, R. Rajar and H. Akagi, 2006. Spatial variations of mercury in sediment of Minamata Bay, Japan. Science of the Total Environment, 368:283-290.

Travnikov, O. and I. Ilyin, 2005. Regional Model MSCE-HM of Heavy Metal Transboundary Air Pollution in Europe. EMEP/MSC-E Technical Report 6/2005.

Travnikov, O. and I. Ilyin, 2009. The EMEP/MSC-E mercury modeling system. In: Mason, R. and N. Pirrone (Eds.). Mercury Fate and Transport in the Global Atmosphere, pp. 571-587. Springer.

Travnikov, O., C.-J. Lin, A. Dastoor, O. Bullock, I.M. Hedgecock, C. Holmes, I. Ilyin, L. Jaegl, G. Jung, L. Pan, P. Pongprueksa, A. Ryzhkov, C. Seigneur and H. Skov, 2010. Global and regional modeling. In: Pirrone, N. and T. Keating, 2010. Hemispheric Transport of Air Pollution 2010. Part B: Mercury, pp. 97-144. Air Pollution Studies No. 16. United Nations.

Travnikov, O., I. Ilyin, O. Rozovskaya, M.Varygina, W.Aas, H.T.Uggerud, K. Mareckova and R. Wankmueller, 2012. Long-term Changes of Heavy Metal Transboundary Pollution of the Environment (1990-2010). EMEP Status Report 2/2012.

Trefry, J.H., R.P. Trocine, M.L. McElvaine and R.D. Rember, 2002. Concentrations of Total Mercury and Methylmercury in Sediment Adjacent to Offshore Drilling Sites in the Gulf of Mexico. Final Report to the Synthetic Based Muds (SBM) Research Group. Florida Institute of Technology.

Trefry, J.H., R.P. Trocine, M.L. McElvaine, R.D. Rember and L.T. Hawkins, 2007. Total mercury and methylmercury in sediments near offshore drilling sites in the Gulf of Mexico. Environmental Geology, 53:375-385.

Tsinghua University, 2006. Improved Estimates of Anthropogenic Mercury Emissions in China. Tsinghua University, October, 2006. 56 pp.

Tvinnereim, H.M., R. Eide and T. Riise, 2000. Heavy metals in human primary teeth: some factors influencing the metal concentrations. Science of the Total Environment, 255:21-27.

Ullrich, S.M., T.W. Tanton and S.A. Abdrashitova, 2001. Mercury in the aquatic environment: A review of factors affecting methylation. Critical Reviews in Environmental Science and Technology, 31:241-293.

Ullrich, S.M., M.A. Ilyushchenko, I.M. Kamberov and T.W. Tanton, 2007. Mercury contamination in the vicinity of a derelict chlor-alkali plant. Part I: Sediment and water contamination of Lake Balkyldak and the River Irtysh. Science of the Total Environment, 381:1-16.

UNEP, 2010a. Study on Mercury Sources and Emissions and Analysis of the Cost and Effectiveness of Control Measures: 'Paragraph 29 Study'. [The report plus the associated data compilations.] UNEP-Chemicals, Geneva. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/Paragraph29Study/Final%20Report%20Para29_5%20Nov%202010.pdf

UNEP, 2010b. Process Optimization Guidance for Reducing Mercury Emissions from Coal Combustion in Power Plants. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/coal/UNEP%20Mercury%20POG%20FINAL%202010.pdf

UNEP, 2011a. Toolkit for Identification and Quantification of Mercury Releases. Guideline for Inventory Level 1. Version 1.1. January 2011. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/Publications/Toolkit/Hg%20Toolkit-Guideline%20Level1-Rev-JAN2011.pdf

UNEP, 2011b. Toolkit for Identification and Quantification of Mercury Releases. Revised Inventory Level 2 Report including Description of Mercury Source Characteristics. Version 1.1. January 2011. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/Publications/Toolkit/Hg%20Toolkit-Reference-Report-rev-Jan11.pdf

UNEP, 2011c. Reducing Mercury Emissions from Coal Combustion in the Energy Sector of China. Prepared for the Ministry of Environment Protection of China and UNEP Chemicals. Tsinghua University, Beijing, China. February 2011. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/coal/FINAL%20Chinese_Coal%20Report%20-%2011%20March%202011.pdf

UNEP, 2011d. Reducing Mercury Emissions from Coal Combustion in the Energy Sector of the Russian Federation. Prepared by the Scientific Research Institute for Atmospheric Air Protection (SRI Atmosphere, JSC), Saint-Petersburg, Russia. November 2011. Online at: www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/coal/Report_Coal_Russia_20FINAL_2016_20Nov2011.pdf

UNEP, 2011e. Global Estimate of Global Mercury Cell Chlorine Capacity. United Nations Environment Programme, Geneva.

UNEP, 2012. Update of 2004 database of global mercury cell chlorine capacity. Online at: www.unep.org/hazardoussubstances/Mercury/PrioritiesforAction/ChloralkaliSector/Reports/tabid/4495/language/en-US/Default.aspx

UNEP/AMAP, 2011. Climate Change and POPs: Predicting the Impacts. Report of the UNEP/AMAP Expert Group. Secretariat of the Stockholm Convention, Geneva. 62 pp.

UNEP/CIMFR-CSIR, 2012. Characterization of the coal fired power sector in India, assessment of the mercury contents in coal fed to power plants and calculation of mercury emissions from the sector. Central Institute of Mining & Fuel Research (CIMFR), Council of Scientific & Industrial Research (CSIR), Department of Science & Technology. 34 pp.

UNEP Chemicals Branch, 2008. The Global Atmospheric Mercury Assessment: Sources, Emissions and Transport. UNEP-Chemicals, Geneva. Online at: www.chem.unep.ch/mercury/Atmospheric_Emissions/UNEP%20SUMMARY%20REPORT%20-%20CORRECTED%20May09%20%20final%20for%20WEB%202008.pdf

US EPA, 2008. Meeting Minutes, April 9, 2008 Meeting between the Portland Cement Association and the USEPA 008 (www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2002-0051-2093).

US EPA, 2011a. Memorandum: Emissions Overview: Hazardous Air Pollutants in Support of the Final Mercury and Air Toxics Standard - M. Houyoux and M. Strum - EPA-454/R-11-014 - November 2011.

US EPA, 2011b. Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards - EPA-454/R-11-012 - November 2011.

US EPA, 2012. US National Emission Inventory 2008 version 2 (April 2012). Online at: www.epa.gov/ttn/chief/net/2008inventory.htm

USGS, 2009/2010. United States Geological Survey. Minerals Yearbook. Volume I: Metals and Minerals. http://minerals.usgs.gov/minerals/pubs/commodity/myb/

USGS, 2012. USGS Minerals Yearbook. Online at: http://minerals.usgs.gov/minerals/

Valente, R.J., C. Shea, K.L. Humes and R.L. Tanner, 2007. Atmospheric mercury in the Great Smoky Mountains compared to regional and global levels. Atmospheric Environment, 41:1861-1873.

van Straaten, P., 2000. Mercury contamination associated with small-scale gold mining in Tanzania and Zimbabwe. Science of the Total Environment, 259:105-113.

Veiga, M.M., J.A. Meech and N. Onate, 1994. Mercury pollution from deforestation. Nature, 368:816-817.

Vermette, S., S. Lindberg and N. Bloom, 1995. Field tests for a regional mercury deposition network - sampling design and preliminary test results. Atmospheric Environment, 29:1247-1251.

Vörösmarty, C.J., M. Meybeck, B. Fekete, K. Sharma, P. Green and J.P.M. Syvitski, 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. Global and Planetary Change, 39:169-190.

Voudouri, A. and G. Kallos, 2007. Validation of the integrated RAMS-Hg modelling system using wet deposition observations for eastern North America. Atmospheric Environment, 41:5732-5745.

Wagner, N.J., T.B. Hlatshwayo and M. Ginster, 2008. A source apportioned mercury mass balance across a coal-based petrochemical complex. Fuel Processing Technology, 89:1351-1357.

Wan, Q., X. Feng, J. Lu, W. Zheng, X. Song, S. Han and H. Xu, 2009a. Atmospheric mercury in Changbai Mountain area, northeastern China I. The seasonal distribution pattern of total gaseous mercury and its potential sources. Environmental Research, 109:201-206.

Wan, Q., X. Feng, J. Lu, W. Zheng, X. Song, P. Li, S. Han and H. Xu, 2009b. Atmospheric mercury in Changbai Mountain area, northeastern China II. The distribution of reactive gaseous mercury and particulate mercury and mercury deposition fluxes. Environmental Research, 109:721-727.

Wang, F. and J. Zhang, 2012. Mercury contamination in aquatic ecosystems under a changing environment: Implications for the Three Gorges Reservoir. Chinese Science Bulletin, special issue, October 2012. doi: 10.1007/s11434-012-5490-7.

Wang, Q., D. Kim, D.D. Dionysiou, G.A. Sorial and D. Timberlake, 2004. Sources and remediation for mercury contamination in aquatic systems - a literature review. Environmental Pollution, 131:323-336.

Wang, S.X., J.X. Song, G.H. Li, Y. Wu, L. Zhang, Q. Wan, D.G. Streets, C.K. Chin and J.M. Hao, 2010. Estimating mercury emissions from a zinc smelter in relation to China's mercury control policies. Environmental Pollution, 158:3347-3353.

Wang, Y.M., D.Y. Wang, B. Meng, Y.L. Peng, L. Zhang and J.S. Zhu, 2012a. Spatial and temporal distributions of total and methyl mercury in precipitation in core urban areas, Chongqing, China. Atmospheric Chemistry and Physics Discussions, 12:10243-10272.

Wang, F., R.W. Macdonald, D.A. Armstrong and G.A. Stern, 2012b. Total and methylated mercury in the Beaufort Sea: The role of local and recent organic remineralization. Environmental Science and Technology, 46:11821-11828.

Wängberg, I., J. Munthe, T. Berg, R. Ebinghaus, H.H. Kock, C. Temme, E. Bieber, T.G. Spain and A. Stolk, 2007. Trends in air concentrations and deposition of mercury in the coastal environment of the North Sea Area. Atmospheric Environment, 41:2612-2619.

Wasserman, J.C., S. Hacon and M.A. Wasserman, 2003. Biogeochemistry of mercury in the Amazonian environment. Ambio, 232:336-342.

Weigelt, A., E. Bieber, C. Temme, H.H. Kock, A. Schwerin, M. Schuetze and R. Ebinghaus, 2012. Speciated mercury measurements in ambient air from 2009 to 2011 at a Central European rural background monitoring site. Proceedings of the 16th International Conference on Heavy Metals in the Environment (ICHMET 2012), Rome, Italy, 23-27 September 2012.

Weiss-Penzias, P., D.A. Jaffe, P. Swartzendruber, J.B. Dennison, D. Chand, W. Hafner and E. Prestbo, 2006. Observations of Asian air pollution in the free troposphere at Mount Bachelor Observatory during the spring of 2004. Journal of Geophysical Research, 111:D10304.

Weiss-Penzias, P., D. Jaffe, P. Swartzendruber, W. Hafner, D. Chand and E. Prestbo, 2007. Quantifying Asian and biomass burning sources of mercury using the Hg/CO ratio in pollution plumes observed at the Mount Bachelor observatory. Atmospheric Environment, 41:4366-4379.

Weiss-Penzias, P., M.S. Gustin and S.N. Lyman, 2009. Observations of speciated atmospheric mercury at three sites in Nevada: Evidence for a free tropospheric source of reactive gaseous mercury. Journal of Geophysical Research, 114:D14302.

Whalin, L., E.-H. Kim and R.P. Mason, 2007. Factors influencing the oxidation, reduction, methylation and demethylation of mercury species in coastal waters. Marine Chemistry, 107:278-294.

Wheatley, B. and M.A. Wheatley, 1988. Methylmercury in the Canadian Arctic environment past and present – natural or industrial? Arctic Medical Research, 47:163-167.

White, E.M., G.J. Keeler and M.S. Landis, 2009. Spatial variability of mercury wet deposition in Eastern Ohio: Summertime meteorological case study analysis of local source influences. Environmental Science and Technology, 43:4946-4953.

WHO, 2010. Children's Exposure to Mercury Compounds. World Health Organization (WHO). Online at: http://whqlibdoc.who.int/publications/2010/9789241500456_eng.pdf

Whyte, D.C. and J.W. Kirchner, 2000. Assessing water quality impacts and cleanup effectiveness in streams dominated by episodic mercury discharges. Science of the Total Environment, 260:1-9.

Wiener, J.G., D.C. Evers, D.A. Gay, H.AS. Morrison and K.A. Williams, 2012. Mercury contamination in the Laurentian Great Lakes region: Introduction and overview. Environmental Pollution, 161:243-251.

Wilhelm, S., 2001. Mercury in petroleum and natural gas: Estimation of emissions from production, processing and combustion. US EPA, Technical report prepared by National Risk Management Research Laboratory. EPA/600/R-01/066.

Wilhelm, S.M., L. Liang, D. Cussen and D.A. Kirchgessner, 2007. Mercury in crude oil processed in the United States (2004). Environmental Science and Technology, 41:134509-134514.

Wilson, S., F. Steenhuisen, J.M. Pacyna and E.G. Pacyna, 2006. Mapping the spatial distribution of global anthropogenic mercury atmospheric emission inventories. Atmospheric Environment, 40: 4621-4632.

Winch, S., D. Fortin, D. Lean and M. Parsons, 2008. Factors affecting methylmercury levels in surficial tailings from historical Nova Scotia gold mines. Geomicrobiology Journal, 25:112-129.

World Bank, 2012, List of GDP PPP per country. Online at: http://data.worldbank.org/data-catalog/GDP-PPP-based-table

Worldsteel Association, 2011. Steel Statistical Yearbook 2011. (Table 41). Worldsteel Committee on Economic Studies, Brussels. Online at: www.worldsteel.org/statistics/statistics-archive/yearbook-archive.html

Wu, Y., S. Wang, D.G. Streets, J. Hao, M. Chan and J. Jiang, 2006. Trends in anthropogenic mercury emissions in China from 1995 to 2003. Environmental Science and Technology, 40:5312-5318.

Xu, L.-Q., X.-D. Liu, L. Sun, Q.-Q. Chen, H. Yan, Y. Liu, Y.-H. Luo and J. Huang, 2011. A 700-year record of mercury in avian eggshells of Guangjin Island, South China Sea. Environmental Pollution, 159:889-896.

Yang, Y., H. Chen and D. Wang, 2009. Spatial and temporal distribution of gaseous elemental mercury in Chongqing, China. Environmental Monitoring and Assessment, 156:479-489.

Žagar, D., A. Knap, J.J. Warwick, R. Rajar, M. Horvat and M. Četina, 2006. Modelling of mercury transport and transformation processes in the Idrijca and Soča river system. Science of the Total Environment, 368:149-163.

Zhang, L., P. Blanchard, D.A. Gay, E.M. Prestbo, M.R. Risch, D. Johnson, J. Narayan, R. Zsolway, T.M. Holson, E.K. Miller, M.S. Castro, J.A. Graydon, V.L. St. Louis and J. Dalziel, 2012a. Estimation of speciated and total mercury dry deposition at monitoring locations in eastern and central North America. Atmospheric Chemistry and Physics, 12:4372-4340.

Zhang, Y., L. Jaeglé, A. Van Donkelaar, R. Martin, C. Holmes, H. Amos, Q. Wang, R. Talbot, R. Artz, S. Brooks, W. Luke, T. Holsen, D. Felton, E. Miller, K. Perry, D. Schmeltz, A. Steffen, R. Tordon, P. Weiss-Penzias and R. Zsolway, 2012b. Nested-grid simulation of mercury over North America. Atmospheric Chemistry and Physics, 12:6095-6111.

# Acronyms and Abbreviations

| | |
|---|---|
| AEF | Abated emission factor |
| Al | Aluminium |
| AMAP | Arctic Monitoring and Assessment Programme |
| AMDE | Atmospheric mercury depletion event |
| AMNet | Atmospheric Mercury Network (US) |
| APCD | Air pollution control device |
| ASGM | Artisanal and small-scale gold mining |
| Au | Gold |
| BAT | Best Available Technique |
| BEP | Best Environmental Practice |
| Br | Bromine |
| CAP | Chlor-alkali production with Hg-technology |
| CAMNet | Canadian Atmospheric Monitoring Network |
| CAPMoN | Canadian Air and Precipitation Monitoring Network |
| CARA | Canadian Clean Air Regulatory Agency |
| CARIBIC | Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container |
| $CH_4$ | Methane |
| CIS | Commonwealth of Independent States (the former Soviet Republics, formed during the break-up of the Soviet Union) |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cu | Copper |
| CVAAS | Cold vapour atomic absorption spectroscopy |
| CVAFS | Cold vapour atomic fluorescence spectroscopy |
| DF | Distribution factor |
| DGM | Dissolved gaseous mercury |
| DMeHg | Dimethyl mercury |
| DOC | Dissolved organic carbon |
| dw | Dry weight |
| E-PRTR | European Pollutant Release and Transfer Register |
| EEA | European Environment Agency |
| EF | Emission factor |
| EMEP | European Monitoring and Evaluation Programme |
| EPA | Environmental Protection Agency (US) |
| EU27 | The 27 Member States of the European Union |
| GAW | Global Atmosphere Watch |
| GDP-PPP | Gross Domestic Product at Purchasing Power Parity |
| 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) |
| GMOS | Global Mercury Observation System |
| GOM | Gaseous oxidised mercury (see also RGM) |
| Hg | Mercury |
| Hg0 | Elemental mercury |
| HgII | Inorganic divalent mercury |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| ISLSCP | International Satellite Land Surface Climatology |
| LRTAP | UNECE Convention on Long-range Transboundary Air Pollution |
| ΣMeHg | Collective reference to MeHg and DMeHg |
| MBL | Marine boundary layer |
| MDN | Mercury Deposition Network (NADP) |
| MeHg | Monomethyl mercury |
| NADP | National Atmospheric Deposition Program (US) |
| NAPRT | North American Pollutant Releases and Transfers (database) |
| NCP | Northern Contaminants Program |
| NEI | National Emission Inventory |
| NFM | Non-ferrous metal |
| NOx | Nitrogen oxides |
| NPRI | National pollutant release inventory |
| $O_3$ | Ozone |
| Pb | Lead |
| $PBM_{2.5}$ | Particulate bound mercury (particle diameter <2.5 µm) |
| PRI | Pollutant release inventory |
| RGM | Reactive gaseous mercury. Over the past five years the term RGM has been replaced by GOM (gaseous oxidised mercury) |
| $SO_2$ | Sulphur dioxide |
| SOP | Standard operating procedure |
| TGM | Total gaseous mercury (non-speciated gaseous mercury). TGM represents the total concentration of all forms of gaseous Hg compounds in ambient air |
| TPM | Total particulate mercury (no defined particle size) |
| UEF | Unabated emission factor |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| USGS | United States Geological Survey |
| VCM | Vinyl chloride monomer |
| 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-PP-coal | Stationary fossil fuel combustion in (major) power plants: Coal |
| BC-L-PP | Combustion of brown coal (lignite) |
| BC-S-PP | Combustion of brown coal (sub-bituminous coals) |
| HC-A-PP | Combustion of hard coal (anthracite) |
| HC-B-PP | Combustion of hard coal (bituminous coals) |
| 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 |
| SC-DR-gas | Stationary fossil fuel combustion in other uses (domestic/residential uses, transport, and use in fisheries, agriculture): Natural gas |
| NG-DR | Combustion of natural gas |
| WAS | Waste |
| WASOTH | Waste and other losses due to breakage and disposal in landfill, etc. |
| WI | Incineration of waste (large incinerators) |

**UNEP Division of Technology,**
**Industry and Economics (DTIE)**
**Chemicals Branch**
Geneva
Switzerland
January, 2013

Job Number: DTI/1667/GE

**www.unep.org**
United Nations Environment Programme
P.O. Box 30552 Nairobi, Kenya
Tel: ++254-(0)20-762 1234
Fax: ++254-(0)20-762 3927
E-mail: uneppub@unep.org

UNEP

AMAP Secretariat
Gaustadalléen 21
N-0349 Oslo
Norway

Tel. +47 22 95 83 40
Fax +47 22 60 44 27

amap@amap.no

AMAP
Arctic Monitoring and
Assessment Programme

ISBN: 978-82-7971-080-6