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Scenarios of global mercury emissions from anthropogenic sources

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HIGHLIGHTS

- Scenarios for global Hg-emissions through 2050 are developed within the GAINS model.
- Air pollution policies are insufficient to stabilize future global mercury emissions.
- Co-benefits for Hg from parallel control of air quality and GHGs are substantial.
- Maximum feasible reduction strategy brings future Hg emissions below today's levels.
- Elemental gaseous mercury dominates other Hg-forms across scenarios and time periods.

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ABSTRACT

This paper discusses the impact of air quality and climate policies on global mercury emissions in the time horizon up to 2050. Evolution of mercury emissions is based on projections of energy consumption for a scenario without any global greenhouse gas mitigation efforts, and for a 2 °C climate policy scenario, which assumes internationally coordinated action to mitigate climate change. The assessment takes into account current air quality legislation in each country, as well as provides estimates of maximum feasible reductions in mercury through 2050. Results indicate significant scope for co-benefits of climate policies for mercury emissions. Atmospheric releases of mercury from anthropogenic sources under the global climate mitigation regime are reduced in 2050 by 45% when compared to the case without climate measures. Around one third of world-wide co-benefits for mercury emissions by 2050 occur in China. An annual Hg-abatement of about 800 tons is estimated for the coal combustion in power sector if the current air pollution legislation and climate policies are adopted in parallel.

1. Introduction

Adverse effects of mercury (Hg) on human health and ecosystems are well recognized and addressed by a wide range of national and international policy instruments (Sloss, 2012). Growing concerns on continuous exposure and the global nature of mercury pollution, due to its transport in the atmosphere, place mercury among pollutants that need to be controlled as effectively as possible. In 2009, the United Nations Environment Programme has taken the decision to develop and ratify a new global legally-binding treaty on mercury by 2013 (UNEP, 2009). Adoption of new Hg-specific policies at local or world-wide scales might be challenging for many countries. It is therefore crucial to enhance not only understanding of sources and current rates of mercury releases, but also to examine possible trajectories of future Hg-emissions.

Projecting mercury emissions is associated with numerous complexities because future Hg levels result from interplay of a range of determinants and policies that address different objectives. Besides the end-of-pipe measures dedicated to Hg-capture, most of air pollution control technologies are capable to co-control also mercury to a certain extend. At the same time, greenhouse gas (GHG) emission mitigation strategies might gain numerous positive side-effects, for example improved energy supply security (Rafaj et al., 2006), smaller burden on human health (Rafaj et al., 2013), as well as reduced exposure to mercury. In this context, it is particularly relevant to quantify the size of potential co-benefits and synergies between abating mercury and other air emissions.

Two recent studies investigated the future global Hg trends by using emission scenarios through 2020 (Pacyna et al., 2010a,b) and through 2050 (Streets et al., 2009). The first study is based on detailed Hg-inventory by country, projected by modifying emission factors to simulate various stringency of mercury control. The second analysis provides long-term estimates for 17 world regions,

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whereby the penetration of flue gas desulfurization drives the degree of mercury abatement. While the above reports provide ranges for possible evolution of mercury trends, they employ rather stylized assumptions on current and planned legislation on air quality.

Our approach for scenario analysis is based on detailed bottom-up representation of air pollution control technologies and policies in each country complemented with legislation on mercury control. For this purpose the IIASA's Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model (Amann et al., 2011a), has been extended to include all major sources and options to reduce mercury emissions. In this way, GAINS scenarios allow to assess impacts of air quality and climate policies on future mercury emissions. We note that anthropogenic emission sources of mercury covered by GAINS contribute by about 30% to the total air releases, while the remainder is attributed to the natural sources and re-emissions (UNEP, 2013).

This paper summarizes results and implications of scenario analysis for key world regions and sources, as well as describes methodological and database framework involved in the assessment. Main sectors responsible for anthropogenic Hg-emissions are examined for the period up to 2050. Potential for further reduction is explored by simulating effects of the worldwide adoption of most efficient measures to abate mercury.

2. Modeling framework

Scenarios of global mercury emissions are developed within the GAINS model, which is a tool to quantify emission levels, costs and impacts of strategies to reduce both air pollutants and greenhouse gases (Amann et al., 2011a). Among the major features of the model is the ability to capture multi-pollutant and multi-effect characteristics of emission control measures. This is particularly suitable for modeling atmospheric releases of mercury, because most of technologies to control conventional air pollutants (e.g., particulate matter, nitrogen oxides, sulfur dioxide – SO_2) are capable to capture mercury or to modify chemistry of mercury in flue gases.

GAINS computes current and future mercury emissions (E^{Hg}) based on activity data (A) in specific combustion and non-combustion sources (s), uncontrolled emission factors (e), removal efficiencies (r) of emission control measures (t) and the extent to which such measures are applied (x). The model also takes into account retention of mercury in the fly ash. Emissions are estimated for each form of mercury (f) released from a set of activity types (p), according the following formula:

$$E^{Hg} = \sum_{f} E_{p,s,t} = \sum_{f,p,s,t} A_{p,s} e_{p,s} (1 - r_{f,t}) x_{p,s,t}$$

Uncontrolled emission factors are derived from mercury contents in combustible fuels or wastes, and from estimates on Hg-impurities in raw materials used in production processes. Emissions of mercury in flue gases are calculated for three major species: elemental mercury (Hg^0) and two oxidized compounds – divalent (Hg^{II}) and particulate bound (Hg_P) mercury. Calculation of mercury by species is important because of their different lifetime and transport characteristics. In addition, control technologies are less efficient in capturing gaseous elemental mercury as compared to oxidized forms. Changes in the mercury speciation in flue gases due to pollution controls are reflected by using the inlet and outlet composition factors.

There are two types of control measures for mercury defined in the GAINS model. The first set of measures are "conventional" air pollution control devices (APCD), which reduce mercury as a side effect of their operation. Removal efficiency of APCDs for Hg is in most cases reinforced if they are adopted simultaneously. Thus, the amplification effect of multiple APCDs is considered in the computation algorithm: the application rate of Hg-removing APCDs is derived as an overlap of rates (x) for individual technologies (Fig. 1). The second set of measures represented in GAINS are those directly dedicated to the capture of mercury.

The GAINS model computes global mercury emissions at the level of 162 individual countries, sub-regions or regional aggregates. It covers the time horizon up to 2050 in 5-years steps. Geographical resolution of the modeling framework applied in this work is provided in the Supplementary material (see ST1). The Hg-emission factors are defined in each region for 15 fuel types used in 35 sectors. In addition, 20 non-combustion emission sources, covering mainly the industrial process and mining activities, are considered. IIASA (2009) provides further details on the GAINS structure.

Basic parameters used for the calculation of Hg-emissions are summarized in Table 1. Region specific emission coefficients for each sector-fuel-combination have been derived from the literature sources. Information on the mercury contents in coal is adjusted by calorific values and estimates on Hg-retention in ash for different combustion conditions. Emission factors for waste combustion are differentiated by regional groups, whereby regions are split into three categories: industrialized (the upper range), medium developed and developing (the lower range). Emission factors for non-ferrous metals smelting reflect the composition of metals-production activities in individual regions.

Similarly, the input parameters for the mercury speciation is based on the literature survey. Because of the lack of country data, the generic values shown in Table 1 are used across all regions. As pointed out by Wu et al. (2010), the speciation of mercury during combustion is associated with large uncertainties, thus more measurements are required to improve the estimates of speciated Hg-profiles. It is also noted, that the initial share of mercury species employed in the calculations represent a split assumed to occur in flue gases before their treatment in the source-specific control devices.

Current and future control of mercury in the key emission sources is simulated in GAINS by an application of about 60 technologies and measures, or their combinations. Implementation of Hg-controls in GAINS follows the approach used for modeling abatement of particulate matter (Klimont et al., 2002) and extends by the multi-pollutant abatement effects for mercury as described above. Control measures range from non-technological options (e.g., banning certain activities, good practices, recycling) to the dedicated end-of-pipe technologies. The main control measures considered in this study for key sectors are listed in Table 2. Removal efficiencies for elemental

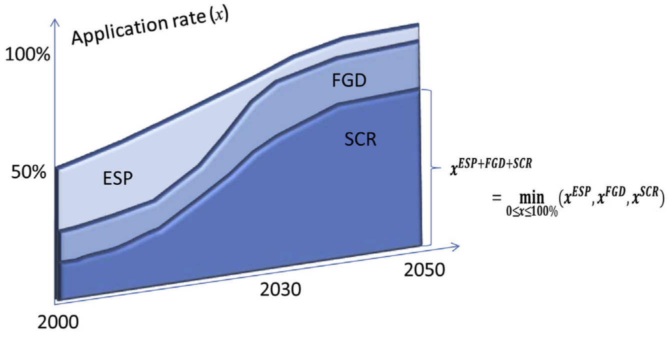

Fig. 1. Multi-pollutant technology approach for Hg-control in GAINS. ESP, FGD and SCR are examples of devices to control emissions of particulates, sulfur and nitrogen oxides (see Table 2 for acronyms).