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TNO-report

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Study to the effectiveness of the UNECE Heavy Metals Protocol and costs of possible additional measures

Phase I: Estimation of emission reduction resulting from the implementation of the HM Protocol

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Summary

In 1998 the UNECE Protocols for Heavy Metals (HM) and Persistent Organic Pollutants (POP) were signed by 35 countries and the European Commission. The Protocols enter into force 90 days after ratification by a minimum of 16 countries; the POP Protocol has entered into force on October 23, 2003 and the HM Protocol entered into force on December 30, 2003. Once the protocols enter into force automatically a review starts. Now that the protocols are in force, the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has asked TNO to execute a study to the effectiveness of the UNECE Heavy Metals Protocol and Persistent Organic Pollutants Protocol and an assessment of possible additional measures with their reductions and costs, based on projections of 2000 emission data to the years 2010, 2015 and 2020.

The study consists of two phases. Phase I comprises the construction of an emission inventory for the year 2000, including actualisation of emission data and projections for 2010, 2015 and 2020, geographical allocation of these emissions, efficiency of the current protocols and a preliminary inventory of possible additional reduction measures. Phase II comprises an estimation of the emission reduction as well as costs of options for revision of the HM/POP Protocols. Phase II will only start after completion of phase I.

The results of the study presented in this report are an European emission inventory for heavy metals for the year 2000 and projected emissions for the years 2010, 2015 an 2020 (Table S1). The inventory is whenever possible based on country submissions of emission data. For the lacking countries, sources or compounds, TNO default emission estimates have been used to complete the inventory. For the compounds for which no or incomplete emission estimate methodology was described in the joint EMEP/ CORINAIR Guidebook, a default methodology was developed. In the majority of the member countries the relevant experts have been contacted and information on the default emission inventory methodology has been transferred to them and included a feed back by the country experts regarding corrections of official emission data as retrieved by TNO.
An indicative comparison between the year 2000 HM emissions and the previous TNO 1990 HM inventory (Berdowski et al, 1997a) showed that between 1990 and 2000 the emission of Cd, Hg and Pb decreased with 42%, 31% and 64%, respectively (Table S1). The HM Protocol focuses on three priority metals (Cd, Hg and Pb) but as a result of the emission reduction measures for these priority, that the emissions of As, Cu, Ni and Zn are simultaneously reduced with 57%, 53%, 65% and 29%, respectively. For Se no 1990 emission data were available and therefore no emission reduction could be calculated. Chromium emissions in 2000 are estimated to be at the same level as 1990. Considerable Cr emission reductions in many countries are counterbalanced by increasing emissions in others; chromium emissions are only expected to significantly decrease if all countries implement the

HM Protocol. However, Berdowski et al. (1997a) did not include Ni production as a major source of Cr. Hence the 1990 Cr emissions are probably underestimated and it is expected that in reality Cr emissions did also decrease from 1990-2000. By contrast the decade 2000-2010 (assuming current ratification of the HM Protocol and compared to the period 1990-2000) is expected to only bring about a large emission reduction for Pb due to the phase out of leaded petrol. However, full implementation of the HM Protocol by all UNECE-Europe countries would bring about considerable HM emission reductions.

Table S1 Emissions of selected heavy metals in UNECE Europe for 2000 and projected emissions for 2010, 2015 and 2020 following two policy scenarios ***BL_CLE_CRHM*** *(Base Line scenario with Current Legislation and Current Ratification (as of April 2005) of HM Protocol) and* ***BL_CLE_FIHM*** *(Base Line scenario with Current Legislation and Full Implementation of HM Protocol).*

Year_policy scenario	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
	Tonnes / yr								
1990	650	501	41879	1284	2289	6078	11930	NA[b)]	27659
2000	377	344	15021	555	2350	2846	4144	501	19503
2010_BL_CLE_CRHM	327	328	8455	449	2328	2642	3750	317	18025
2015_BL_CLE_CRHM	326	325	8578	444	2489	2698	3649	321	18369
2020_BL_CLE_CRHM	323	326	8835	438	2645	2772	3426	325	19006
2010_BL_CLE_FIHM	226	318	6566	332	884	2033	3063	285	12973
2015_BL_CLE_FIHM	222	315	6689	325	894	2070	2903	290	13218
2020_BL_CLE_FIHM	217	316	6946	318	900	2126	2622	294	13766

[a)] 1990 data taken from Berdowski et al. (1997a) for indicative comparison. Countries not covered by Berdowski et al. are represented by their year 2000 emissions

[b)] NA = Not Available.

To project the year 2000 emissions to future years (2010-2020) assumptions have to be made about the change in activities over time. The projection of activity data is as much as possible based on the baseline scenarios developed in the framework of the Clean Air for Europe (CAFE) program (Amann et al., 2005). These include two energy pathways; a baseline scenario (BL) without climate policies and the Climate policy energy pathway (CP). To investigate the sensitivity of the HM projections for the choice of energy pathway, projections are made for both energy pathways. In general, the climate policies are found to have a small but positive effect on the emissions of HM, mostly due to a reduced use of coal. Comparison of emissions for the CP scenario and the BL scenario illustrates that the projections are not very sensitive to the exact definition of the energy pathway: For HM emission, reduction measures and technologies are much more important. The year 2000 emissions have been projected to the years 2010, 2015, and 2020 following two policy scenarios; a Base Line scenario with Current LEgislation and Current Ratification of the UNECE HM Protocol (BL_CLE_CRHM) and a Base Line scenario with Current LEgislation and Full Implementation of HM Protocol (BL_CLE_FIHM). The results indicate that for countries that have to comply with the EC directives and /or 2nd S protocol, the HM Protocol will result in small reductions since the majority of the obligations are already covered. The EC is a party to the CLRTAP and the UNECE protocols and thereby bound to integrate the obligations of these protocols in EC legislation. Therefore, many of the foreseen emission reductions that can be achieved through the HM Protocol are also achieved through e.g. implementation of the IPPC, Waste and LCP EC directives and /or 2nd S protocol. The conclusion is that for countries that comply with these EC directives and /or 2nd S protocol, compliance with the HM Protocol is relatively easily achieved. Vice versa, countries that comply with the HM Protocol can relatively easily comply with the relevant parts of the EC directives. The countries that have not ratified the HM Protocol, are not a member of the EU-25 and have not ratified the 2nd S protocol show a truly different pattern. Here the emission increases going from 2000 to 2010, 2015 and 2020 for the BL_CLE_CRHM scenario. However, when these countries would comply with the HM Protocol (BL_CLE_FIHM scenario) major (~ 50%) emission reductions are achieved with the exception of Hg because Hg is mostly emitted in the gaseous phase and less effectively addressed by dust reduction measures.

More detailed observations from the projected HM emissions in UNECE Europe for 2010, 2015 and 2020 following the two policy scenarios are:

- For Pb, Se and As considerable reduction (20~40%) is achieved going from the year 2000 to 2010 following the baseline scenario and current ratification of the HM Protocol.
- The lead emissions strongly decline going from 2000 to 2010 due to the phase out of leaded gasoline. The remaining limit value of Pb in fuel however causes road transport to remain an important source of Pb.
- Emission of Cr is the only HM that is expected to grow in emission compared to 2000. This is due to activity increase in (Ni production) countries that have currently not ratified the protocol.
- If all countries of UNECE-Europe implement the HM Protocol the projected emissions are considerable reduced (20-60%) compare to the year 2000 for all HM except Hg. This is because Hg is mostly emitted in the gaseous phase and is poorly mitigated by the currently proposed measures.
- the difference in HM emissions under the two policy scenarios is larger than the emission changes over time within a policy scenario (e.g. going from 2010 to 2020).

Full implementation of the HM Protocol is an important step in HM emission reduction. The relative small importance of the projection years (2010-2015-2020) can be explained by 1) our assumption that measures following implementation of the HM Protocol will be in effect before 2010 (in both policy scenarios) and little additional measures are yet defined for the period after 2010.

A key source analysis of the projected emissions assuming full implementation of the UNECE HM Protocol is made to identify remaining source strengths which subsequently are discussed in terms of their potential for (further) reduction. After full implementation and compliance with the HM Protocol the following source sectors are expected to be the main HM emissions sources: Combustion of fossil fuels for heat and power production, Cement production, Iron and steel industry, Road transport, Industrial and residential combustion and Production of copper and zinc (Table S2). However, in some cases the emissions may be inaccurate due to a lack of good data e.g., data on the lead content in unleaded fuel and the amount of mercury in current and future municipal waste.

Table S2. Relative contribution of source sectors to remaining HM emissions upon full implementation of the HM Protocol by all UNECE-Europe countries.

Source sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public power and heat	18	40	6	22	8	5	40	18	10
Residential combustion	15	8	4	11	10	9	10	3	7
Industrial combustion and processes	60	46	42	66	75	36	45	77	65
Road transport	4	0	45	0	3	31	2	1	13
Non-road transport	0	0	2	0	0	17	2	1	0
Waste incineration	2	5	1	1	3	2	0	0	5
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

It is estimated that full implementation of the HM Protocol will - as a side effect – result in particulate matter (PM) emission reduction; ~ 3.7 Mt TSP (total suspended particles), 1.2 Mt PM10 and 0.28 Mt PM2.5. Compared to the total European PM emissions in 1995, this is ~ 25% of total TSP, 16% of total PM10 and 6% of total PM2.5 emission, with the largest reduction achieved in the power generation sector. In this study the choice is made to first implement autonomous measures (e.g. IPPC directive for the EC25) and than quantify the additional PM reduction due to implementation of the HM Protocol. If the procedure would be followed differently (first HM Protocol, than (other) autonomous measures) the side effect of the HM Protocol on PM reduction is much larger.

Finally, the emission projections under full implementation of the HM Protocol can be used as an approximation of the remaining HM emissions in the future. A key source analysis of these projected emissions provides insight in the remaining source strengths which subsequently are discussed in terms of their potential for (further) reduction. The result of this analysis is that possible options for further HM emission reduction are proposed for Heat and power production sector, Cement production, Sinter plants, Blast furnaces, Electric arc furnaces, Basic oxygen furnaces, Open hearth furnaces, Coke ovens, Production of copper and zinc (including Imperial Smelting) and Road transport (fuel composition).

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1. Introduction

In 1998 the UNECE Protocols for Heavy Metals (HM) and Persistent Organic Pollutants (POP) were signed by 35 countries and the European Commission. The protocols enter into force 90 days after ratification by a minimum of 16 countries. As a result of this the POP Protocol has entered into force on October 23, 2003 and the HM Protocol entered into force on December 30, 2003.

Within the UNECE CLRTAP it has been agreed that Germany leads the Task Force on Heavy Metals. The work plan of the Task Force consists amongst others of an update of Best Available Techniques (BAT) and emission limit values as an input to possibly revise the Technical Annexes to the protocol. The Netherlands have offered to do work on emissions and projections of HM. This work should not only improve emission data but would also asses further possible reduction measures with their associated costs. The Netherlands and Canada are co-lead countries for the Task Force on POP and will facilitate a similar assessment for POPs. During 1996/1997 TNO-MEP performed an identical assessment including incremental measures and costs, based on projections of 1990 emission data to the year 2010 (Berdowski et al. 1997a; 1997b, 1998). In 2003 the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has asked TNO to execute a similar study consisting of two phases.

Phase I comprises the construction of an emission inventory for the year 2000, including actualisation of emission data and projections for 2010-2015-2020, geographical allocation of these emissions, efficiency of the current protocols and a preliminary inventory of additional reduction measures. Also, Phase I will make a preliminary semi-quantitative assessment of possible options to revise the Protocols. The results of Phase I for the heavy metals are reported in this report.

Phase II comprises an estimation of the emission reduction as well as costs of options for revision of the HM/POP Protocols. The options to be considered in Phase II will be discussed with the Task Force on POP and the Task Force on Heavy Metals .The rationale behind Phase II is that during the review of the HM and POP Protocols, scheduled to take place after the entry into force of the protocols, there will be a need for an assessment of the potential for further emission reduction and costs through possible revision of the Protocols.

1.1 Scope of the study

An inventory and projection of emissions of HM and POP from sources in European countries will show the effectiveness of the UNECE HM and POP Protocols (Phase I). On base of the inventoried and projected emissions conclusions can be drawn with respect to the effectiveness and attained emission reduction as a result of the implementation of the HM and POP Protocols. The results can also be used in a discussion on a revision of the protocols in the (near) future. In addition, a literature scan to possible options for revision of the protocols is performed. This study will provide the Task Force on Heavy Metals and the Task Force on POPs with additional information on options to revise the Protocols. The second phase (Phase II) will estimate the costs as well as the attained emission reduction upon taking additional measures.

1.2 Substances

The emission inventory is made for the three priority metals Cd, Hg and Pb in the HM Protocol and 6 other HM (Table 1). The latter are included since their emissions are often simultaneously reduced as a consequence of reduction measures for the three priority HM In the UNECE Emission Inventory Guidebook selected air pollutants are listed as well as a rather extensive collection of their sources. However not all substances are currently covered so additional efforts will have to be made to develop emission estimation methods. Furthermore, the effects on particulate matter emission (PM_{10} $PM_{2.5}$) of especially the HM emission reductions is included in this study.

Table 1 Heavy metals addressed in the present study.

Priority Heavy Metals[a)]	Other Heavy Metals
Cadmium (Cd)	Arsenic (As)
Lead (Pb)	Chromium (Cr)
Mercury (Hg)	Copper (Cu)
	Nickel (Ni)
	Selenium (Se)
	Zinc (Zn)

a) The so-called priority HM are addressed by the HM Protocol.

1.3 Countries and domain covered by the study

The domain of study is the European part falling under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) and thus does not include Canada and the United States. The 44 countries covered in the study are listed in Table 2. Throughout the report we refer to the countries listed in Table 2 as UNECE-Europe. For the inventory and projections the countries will be dealt with as they exist now. Turkey includes its Asian part. The Eastern boundary of European Russia is described with 60º East longitude (cf EMEP).

Table 2 The UNECE[a] countries covered by the study, ISO 3 country codes in brackets.

Albania (ALB)	Ireland (IRL)
Armenia (ARM)	Italy (ITA)
Austria (AUT)	Kazakhstan (KZA)
Azerbaijan (AZE)	Kyrgyzstan (KGZ)
Belarus (BLR)	Latvia (LVA)
Belgium (BEL)	Lithuania (LTU)
Bosnia and Herzegovina (BIH)	Luxembourg (LUX)
Bulgaria (BGR)	Netherlands (NLD)
Croatia (HRV)	Norway (NOR)
Cyprus (CYP)	Poland (POL)
Czech Republic (CZE)	Portugal (PRT)
Denmark (DNK)	Republic of Moldova (MDA)
Estonia (EST)	Romania (ROM)
Federal Republic of Yugoslavia (YUG)	Russia (RUS)
Finland (FIN)	Slovak Republic (SVK)
Former Yugoslav Republic of Macedonia (MKD)	Slovenia (SVN)
France (FRA)	Spain (ESP)
Georgia (GEO)	Sweden (SWE)
Germany (DEU)	Switzerland (CHE)
Greece (GRC)	Turkey (TUR)
Hungary (HUN)	Ukraine (UKR)
Iceland (ISL)	United Kingdom (GBR)

[a] The UNECE countries not covered by the study are Andorra, Canada, Liechtenstein, Malta, Monaco, San Marino, Israel, Tajikistan, Turkmenistan, United States and Uzbekistan. These countries are not included because they are outside of the European domain or because their emissions are thought to be very limited.

This report presents the results of the inventory in the form of tables, maps and figures. The results are a mixture of official country submitted data and default emission estimates by TNO because not for all countries, source categories and substances official emission data are available. The procedures followed to come to the current inventory and projections are described in chapters 2, 3 and 4. The results on the UNECE-Europe scale and on the scale of country groups is presented in chapter 5. The results for the individual countries are presented in annex 4. A more detailed breakdown of the emissions per country by source category and fuel type is available on the CD-ROM attached to the back cover of the report (annex 6). The potential for further reduction of HM emissions, provided that all countries have implemented the HM Protocol, is discussed in chapter 6.

2. Procedures and official emission data

The emission inventory for the year 2000 necessary for assessment of the effectiveness of the UNECE HM Protocol, the emission reductions and the costs of possible additional measures is based on official data submissions by the countries to EMEP. However, during the time that the presented study was executed (2004-2005) many reportings are incomplete (Ilyin and Travnikov, 2003). A complete inventory is required to make a proper assessment of both the effectiveness of the protocols as well as the reductions and costs of possible additional measures. Therefore, the procedure followed is first to obtain the latest version of the emission data submitted by the countries. Several lists of national experts and/or national focal points were combined to obtain coverage for all countries. An overview of the country contacts that were consulted is presented in Annex 1.

2.1 Response from countries and available official submitted emission data

The first submission to the countries was done by surface mail and e-mail and included an introductory letter of the project by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM). Subsequent communication was done by e-mail and sometimes the experts or national focal points redirected us to the most appropriate national expert. In a few cases country overviews were sent by fax if an e-mail address was not available or e-mail did not give any response. The advantage of e-mail communication is that it is quick and allows relatively easy correction by national experts in the datasheets submitted. The contact and information exchange moments are listed in Table 3.
TNO attempted to close the gaps in the inventory by actively participating in a dialogue between TNO and experts from individual countries. However, since phase I needed to be completed within a fixed time frame (1,5 year) strict deadlines are defined for submitting additional data that allow ample time for the countries to react and at the same time allow the project to proceed according to plan. Countries have been contacted twice during the creation of the final inventory by submitting overviews of the preliminary national emission data to the country contacts listed in Annex 1. If no country data became available, TNO proposed a default emission that was subject to country review including a limited time to react and/or provide corrections (December 2004, Table 3). The methodology to derive the TNO default emission estimate is described in chapter 3. Table 3 also states which fraction of the countries responded to the mailing. However, it should be realized that the questions were phrased in such a way that if a country has no comments and/or agrees with the submitted data e.g., because they are in line with the official submitted emission data to EMEP, no reaction was necessary. Therefore, Table 3 merely illustrates that there was an active dialogue and that countries, if they felt the need to react, indeed used this opportunity. For example, the last contact round

after December 2004 still resulted in adjustments due to country responses. Corrections have been made up to April 1, 2005.
The starting point of the emission inventory are the official data submissions by the countries to EMEP. The TNO estimates are only used if no country data are available and to spatially distribute the emissions as described in chapter 3. However, in exceptional cases where the gap between official country data and TNO expert estimates is large (> factor 3) and comparison with other country data suggest that the official data may be unrealistic, TNO estimates may overwrite an official emission figure. This is done to make the overall UNECE-Europe emission inventory a reliable data source for quantification of emission reductions, key source analysis and identification of possible additional measures.

Table 3 Time table of national expert contacting and responses and information exchange with the EG/TF[a] HM and TF POP.

Date	Nature of communication
March 2004	Powerpoint presentation of the study and its goals in the TF HM and TF POP
April 1 2004	Letter introducing the project and asking for verification of retrieved official submitted data and/or requesting emission data for missing pollutants or source sectors. A letter supplemented with an overview of the official emissions has been sent to the countries. They were kindly asked to inspect the values and, if necessary, to provide the correct and/or most up to date official emission data. This letter has been followed by an email as a reminder at the end of April 2004 ↳*Response: 48 % (21/44) of the countries responded to this mailing.*
June 2004	Deadline country reactions
December 14, 2004	E-mail supplemented with an overview of the final inventory has been sent to the countries to inform them of the draft final country emissions by source sector (Merged official emissions and TNO estimates) See Annex 1 for country contacts ↳*Response: 23% (10/44) of the countries responded to this mailing.*
Feb / March 2005	Powerpoint presentation of progress reported to the TF HM and TF POP
August 2005	Mailing of final report

[a] As of December 2004 the Expert Group Heavy Metals became the Task Force Heavy Metals

3. Methodology for the TNO reference database

The study makes an emission inventory for Heavy Metals for year 2000 based on submissions of emission data from the Parties to the Convention on LRTAP (chapter 2). To fill gaps for species and/or sources where country submissions lacked data, TNO has prepared a default emission database for the base year 2000. This database is referred to as the TNO reference data base, the procedure to come to these default emissions estimates is described in this chapter. For the countries, sources or compounds lacking in official submissions the reference database is used to complete the inventory. The TNO reference emission inventory for the year 2000 is a “classical” emission inventory assuming a linear relation between the intensity of an activity $AR_{activity}$ (“Activity Rate”) and the emission ($E_{pollutant}$) for each activity. The emission factor is the proportionality constant $EF_{activity,pollutant}$.

$$E_{Pollutant} = \sum_{activities} AR_{activity} \times EF_{activity,\,pollutant}$$

Compilation of the emission inventory involves the collection of (time series of) country level activity data and country specific emission factors. The result of the merging of the officially submitted emission data (chapter 4) and the TNO reference (default) emission database will be a final, completely filled emission database for the year 2000. The procedure for the merging is discussed in chapter 4, section 4.3. The reference database described in this chapter is also used to spatially distribute the final merged emission database (see section 3.8). Once the year 2000 data base is established a new difficulty inherent in the followed approach is the projection of emissions to 2010, 2015 and 2020. The penetration of new technologies and better fuel qualities into the system is not explicitly included in the reference data base and not available for the official database. The solution chosen in the present study to overcome this problem is the use of scaling factors and development of indexes for the future years that can be applied to the year 2000 inventory. For a broader discussion of the air emission inventory models frequently used at TNO including the upgrading of the classical activity rate times emission factor approach to a system which allows retrospective and prospective time series (“projections”) analysis we refer to Pulles et al. (2005).

3.1 Source categories

The extensive collection of source types in both the Atmospheric Emission Inventory Guidebook and the HM/POP Technical Annexes is the basis of the source selection for the inventory. However, several source types mentioned in the Atmospheric Emission Inventory Guidebook and Technical Annexes can be expected to give only minor contributions to national or regional total emissions of substances involved. For a pragmatic implementation of the inventory and presentation of the results the individual sources distinguished in the inventory are aggregated on a higher level by source category (Table 4). A detailed breakdown of the country emissions by source and fuel categories is available on the CD-ROM attached to the back-cover of this report.

Table 4 Source categories defined in the HM and POP inventory.

Sector Code	Description
PHP	Public heat and power; Excludes refineries
RCO	Residential, commercial and other; Includes combustion in agriculture
IND	Industry; Includes both combustion and process emission, and refineries and fossil fuel production
SPU	Solvent and product use; New and existing stocks; Includes wood preservation
ROT	Road transport
NRT	Non-Road transport
WAS	Waste disposal
AGR	Agriculture; Excludes combustion emission in agriculture
TOTAL	Total of all sectors

3.1.1 Activity data

The activity data for the year 2000 is obtained from different sources. The most important data sources are the International Energy Agency (IEA, 2002), The 'Industrial Commodity Production Statistics Dataset 1950-2001' (UN, 2003), Steel statistical yearbook 2003 (IISI, 2004), and the U.S. Bureau of the Census (2004). The major source categories are shown in Table 4 but the activity data are collected on a much lower level referred to as CRFsub. The activities considered in the present HM study are listed in Annex 3.

3.1.2 Emission factors for year 2000

The emission factors are obtained from the latest EMEP CORINAIR guidebook (EMEP/CORINAIR, 2003) and the European Emission Inventory for HM and POP for 1990 (Berdowski et al., 1997a). If no emission factors are available other general guidebooks are scanned e.g., PARCOM ATMOS emission factor manual (Van der Most and Veldt, 1992). Updated values are used if available and appropriate. However, no additional research is undertaken to revise emission factors. The emission factors as published in the EMEP CORINAIR guidebook are assumed to be valid for 1990 and 2000.

3.2 Work procedure and process for Phase I

The reference inventory made in Phase I for the years 1990 and 2000 was based on official data submissions by the countries to EMEP. However at the moment of this writing many reportings are incomplete, both for HM and POP (see also the draft EMEP technical reports 4/2003 & 5/2003). The procedure was to check the submitted data and file a request for missing data from the countries for inclusion in the emission inventory. TNO attempted to close the gaps in the inventory by actively participating in a dialogue between TNO and individual countries. However, since phase I needed to be completed within a year there were strict deadlines for submitting additional data that allowed ample time for the countries to react and at the same time allowed the project to proceed according to plan. If no country data became available, TNO proposed a default emission that was subject to country review including a limited time to react and/or provide corrections.

The source activity rates are projected to future years based on European scenarios developed in the framework of the Gotenburg protocol and the CAFE-program for energy consumption, physical industrial production, agricultural production and waste generation (Amann et al., 2005). The emission control scenarios include implementation of all agreed and/or foreseen national and international policies, including the UNECE HM Protocol for the countries that ratified. For countries that did not (yet) ratify the protocol the additional emission reduction - on top of the earlier mentioned measures - due to implementation of the HM Protocol are estimated. The result is a database with national annual sector totals for the reference years 2000, 2010, 2015 and 2020, that can be spatially distributed on the EMEP 50 x 50 km grid using the format proposed by CLRTAP (NFR-2).

3.3 Policy scenarios for emission projections

In order to assess the emission reduction to be expected from the implementation of the HM Protocol on top of other already planned emission control measures, two policy scenarios are considered. The first projection will be based on the implementation of:

- National policies, such as elimination or restriction of the use of a certain chemical and/or emission limit values for stationary sources.
- Measures agreed internationally by the industry, as there can be mutual agreements to reduce air emissions in specific braches.
- The UNECE Protocols for substances other than HM and POP such as the 2nd Sulphur Protocol.
- EU Policy regarding the use of certain substances or air emission limit values for specific sources as described in e.g., the waste directive and the large combustion plants (LCP) directive.
- The scheduled implementation of the EU IPPC BAT directives for many important sources of air emissions.

– The UNECE HM Protocol for those countries that have ratified the Protocol.

A listing of the HM reduction measures considered and reference of further documentation describing the directive or protocol is presented in Table 5 and section 3.4.

Table 5 Listing of the HM emission reduction measures that are stepwise implemented in the database for the projections of HM emissions in 2010, 2015 and 2020.

ID	Measure Description	Measure documentation
1	No Measure	
2	EuroChlor voluntary reduction program for the Chlor-alkali-industry	http://www.eurochlor.org/tools/sustainability/sustainability.htm
3	UNECE 2nd S Protocol	http://www.unece.org/env/lrtap/fsulf_h1.htm
4	UNECE HM Protocol	http://www.unece.org/env/lrtap/hm_h1.htm
5	IPPC Directive 96/61/EC	http://europa.eu.int/comm/environment/ippc/
6	LCP Directive 2001/80/EC	http://europa.eu.int/comm/environment/air/stationary.htm#1
7	Municipal Waste Directive 2000/76/EC	http://europa.eu.int/comm/environment/air/stationary.htm#1

This first base line policy scenario is referred to in the present study as

BL_CLE_CRHM (Base Line scenario with Current LEgislation and Current Ratification of HM Protocol (as of April 2005))

Then a second policy scenario is applied that includes all of the above mentioned emission reduction measures and the complete implementation of the UNECE HM and POP protocols by all UNECE-Europe countries. This second policy scenario is referred to as

BL_CLE_FIHM (Base Line scenario with Current LEgislation and Full Implementation of HM Protocol)

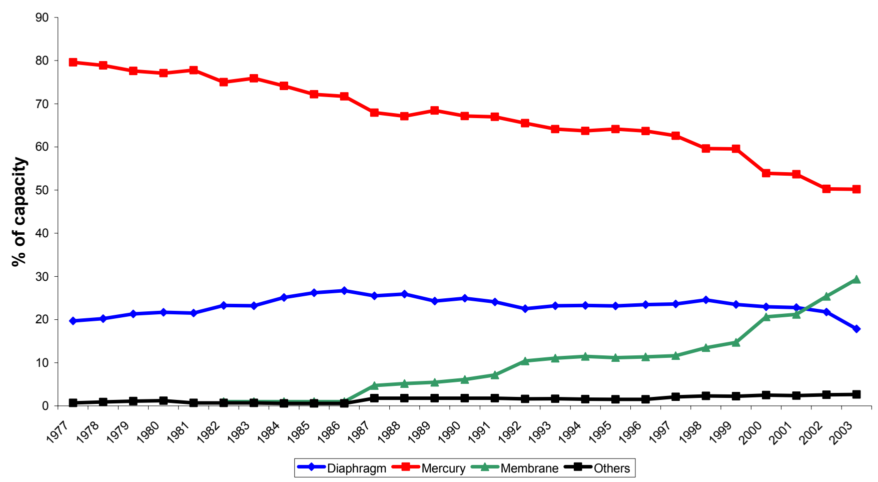
The incremental effect of full implementation the HM Protocol will be assessed by comparison of the results of the scenario calculations. It will show the effect of full implementation of the protocol with respect to the current situation regarding the countries that have ratified. Moreover, it allows quantification of the additional emission reduction that can be expected provided that all UNECE-Europe countries ratify the protocols.

3.4 Description of implemented autonomous measures

3.4.1 Voluntary reduction program for Hg emission from the Chlor-alkali-industry

Chlorine is produced by four technologies – mercury, diaphragm, membrane and, in small quantities, by electrolysis of hydrochloric acid and fused salt. Diaphragm technology has historically been based on asbestos. Companies are moving towards newly-developed non-asbestos separators or converting to membrane technology. Mercury cells are being replaced by membrane technology. Figure 1 illustrates that that in the year 2000 ~50% of the chlorine production is manufactured with non-mercury emitting technologies. A voluntary target of 1.0 gram of mercury per tonne of mercury cell capacity was set in 1998 by Euro Chlor companies to be reached on a national basis by 2007. The participating countries were initially those in Western Europe. Efforts are now being made to extend this to all companies in countries that acceded to the EU in 2004 (Euro Chlor 2002; 2004).

Manufacturing Processes



Compliance with commitments 2003

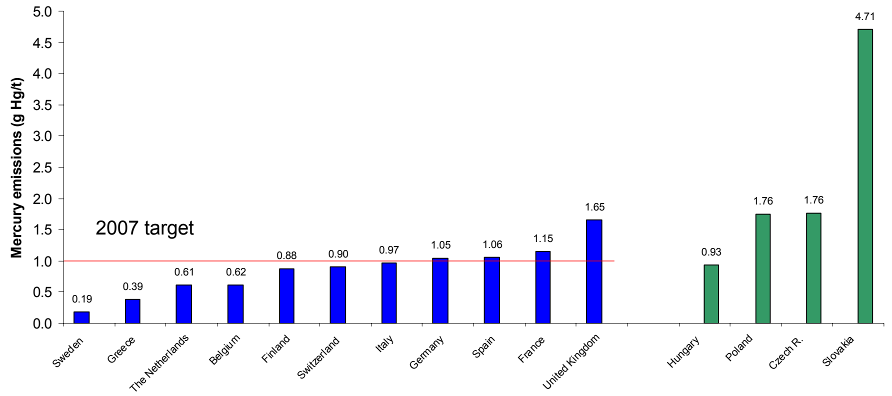


Figure 1 *Compliance with commitments made by companies that participate in Euro-chlor in 2003 (Note: East European members are not part of the voluntary commitment yet but are shown for completeness). (Source Eurochlor 2004).*

Euro Chlor (2002) lists the commitments that participating Chlor-alkali industries have agreed upon; i) no new mercury chlor-alkali plants are to be installed, ii) redundant mercury cells are not to be shipped to third parties, iii) individual plant emissions are reported and audited and finally, iv) the end of existing mercury plants is in or before 2020. Thus the voluntary commitment of the Western European producers is that all conversions for chlorine/caustic soda will have taken place by 2020 (Euro Chlor 2004). From the above information it can be derived that:

– All western European Euro-chlor companies will be below the target value of 1.0 gram of mercury per tonne of mercury cell capacity in 2010 with the exception of Slovakia and countries not listed in Figure 1.

- The average mercury emission of non-western countries in 2010 = 2.5; 2015 = 1.5 g/ton.
- There will be no mercury plants existing by 2020. A simple linear decrease of the mercury capacity from the year 2000 level (54%) to zero in 2020 appears to be too optimistic given the decline rate in Figure 1. For 2010 we assume 45% mercury capacity, 30% in 2015 and 0% in 2020.

3.4.2 The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions

The Convention on Long-Range Transboundary Air Pollution (CLRTAP) has been extended by eight protocols. As part of the autonomous measures we consider the 1994 Protocol on Further Reduction of Sulphur Emissions which entered into force 5 August 1998. Compliance with the 2nd S protocol has an effect on the HM emissions because some of the S reduction measures necessary for compliance can only be implemented after particulate matter (PM) emissions are (further) reduced. Advanced desulphurization technology involving effective PM emission control as a result of the 2nd S Protocol is expected to be implemented in large (>50MWth) coal-fired combustion plants in the public power generation and industry sectors. Sulphur abatement measures for oil-fired combustion plants do generally not bring about end-of-pipe control techniques and therefore the effect on HM emission is expected to be limited. Some effect on PM emission due to 2nd S Protocol is also foreseen in the non-ferrous metals production sector as a result of sulphur capture during ore roasting processes. As HM are emitted in or attached to particles, reduction of PM emission will result in HM reduction. As of 6 May 2005, 25 Parties have ratified the protocol, including 23 countries inside of the inventory domain (Annex 2). For these countries we have made assumptions on the reduction of PM emissions as a consequence of the 2nd S protocol. The complication with predicting HM reduction due to dust emission limit values is that 1) HM are preferentially found in the smaller size fractions of PM and not necessarily proportionally reduced and, 2) some HM (Hg, Se) are only partly emitted as particulates. The translation of dust emission reduction into an approximated HM emission reduction is discussed in section 3.6.

3.4.3 Integrated Pollution Prevention and Control (IPPC) directive

The EU has common rules on permitting for industrial installations. These rules are set out in the so-called IPPC Directive of 1996 (EC, 1996). IPPC stands for *Integrated Pollution Prevention and Control*. In essence, the IPPC Directive is about minimising pollution from various point sources throughout the European Union. All installations covered by *Annex I* of the Directive are required to obtain an authorisation (permit) from the authorities in the EU countries. Unless they have a permit, they are not allowed to operate. The permits must be based on the concept of Best Available Techniques (or BAT), which is defined in Article 2 of the Direc-

tive. In many cases BAT means quite radical environmental improvements and sometimes it will be costly for companies to adapt their plants to BAT. To impose new and considerably tougher BAT rules on all existing installations in the European Union could jeopardise many European jobs, and therefore the Directive grants these installations an eleven year long transition period counting from the day that the Directive entered into force. For further information on the IPPC directive we refer to the European IPPC Bureau (http://eippcb.jrc.es/). The European IPPC Bureau exists to catalyse an exchange of technical information on best available techniques under the IPPC Directive 96/61/EC and to create reference documents (BREFs) which must be taken into account when the competent authorities of Member States determine conditions for IPPC permits.
In the present study we assume that all EU countries need to comply with the IPCC directive by 2010. However, it is possible that this is too optimistic for the expansion of the EU to the EU-25. Therefore, some of the autonomous HM emission reductions foreseen may possibly be reached in 2015 instead of 2010. The impact of the IPPC directive has been quantified for the source types that are explicitly defined in the UNECE HM Protocol. However, this implies that a possible HM emission reduction due to compliance with the IPPC directive in some sectors presently not covered by the HM Protocol may be overlooked. In phase two of this project, a further exploration of the impact of the IPPC directive on remaining source sectors that are selected on the basis of the key source analysis is foreseen. In general, the IPPC directive has an important impact on the emission of HM since the process and emission control technologies that are prescribed by the IPPC Directive in the BREF Documents will result in particulate matter concentrations equal and/or below the HM Protocol limit values.

3.4.4 Limitation of emissions into the air from large combustion plants (LCP)

The so-called LCP directive (2001/80/EC) of the European Parliament and of the Council of 23 October 2001 applies to combustion plants, the rated thermal input of which is equal to or greater than 50 MW, irrespective of the type of fuel used (solid, liquid or gaseous) (EC, 2001b). Member States shall establish, starting in 1990 and for each subsequent year until and including 2003, a complete emission inventory for existing plants covering SO_2 and NO_x (a) on a plant by plant basis for plants above 300 MWth and for refineries; (b) on an overall basis for other combustion plants to which this Directive applies. The directive contains emission limits for sulphur dioxide, nitrogen oxides and dust, varying according to the age and capacity of the plants, as well as the type of fuel burned. It not only tightens up the requirements for new plants, but also gives emission limits for existing ones.

3.4.5 Directive on the incineration of waste

The directive (2000/76/EC) on the incineration of waste covers the incineration of hazardous (formerly Directive 94/67/EC) and non-hazardous (89/369/EEC and 89/429/EEC) waste (EC, 2000b). The new Directive will prevent or – where that is not practicable- reduce as far as possible negative effects on the environment caused by the incineration and co-incineration of waste. In particular, it should reduce pollution caused by emissions into the air, soil, surface water and groundwater, and thus lessen the risks that these pose to human health. This is to be achieved through stringent operational conditions and technical requirements and by setting up emission limit values for waste incineration and co-incineration plants within the Community.
Although the volume of waste incineration is forecast to increase across the EU in the near future, the Directive will lead to significant reductions in emissions of several key pollutants. According to the EC, considerable reductions will be achieved for heavy metals; emissions of cadmium throughout the EU are expected to fall from 16 tonnes per year in 1995 to around 1 tonne in 2005 and mercury emissions should fall from an annual 36 tonnes to around 7 tonnes (EC, 2000b and http://europa.eu.int/comm/environment/air/stationary.htm#1). The limit values for incineration plant emissions to atmosphere are set out in Annex V to the Directive. They concern heavy metals, dioxins and furans, carbon monoxide (CO), dust, total organic carbon (TOC), hydrogen chloride (HCl), hydrogen fluoride (HF), sulphur dioxide (SO_2), nitrogen monoxide (NO) and nitrogen dioxide (NO_2).
The limit values for co-incineration plant emissions to atmosphere are set out in Annex II of the directive (EC, 2000b). In addition, special provisions are laid down relating to cement kilns, other industrial sectors and combustion plants which co-incinerate waste. The Directive will apply to existing plants as from 28 December 2005 and to new plants as from 28 December 2002. The deadline for implementation of the legislation in the member states is 28.12.2002. This implies that for the projection of emission data in 2010, 2015 and 2020 all member states have to comply with the limit values set out in the annexes to the directive.

3.5 Partitioning of heavy metals in emissions to air

The heavy metals Cr, Ni, Cu, Zn, Cd and Pb, are usually emitted into the atmosphere as fine particulate matter (e.g. Puxbaum, 1991). For instance automotive lead is not emitted in the gaseous form by more than 10% (Corrin and Natusch, 1979). However, Hg, As and Se may exist in relevant amounts in the gaseous phase. HM emission reductions are often achieved by particulate matter emission reduction techniques. This implies that emission of HM in the particulate form or attached to the particulate matter will be reduced with the same efficiency as PM but the reduction percentages cannot be applied without correction to the three volatile elements (Hg, As, Se). In this study we assume Cr, Ni, Cu, Zn, Cd and Pb to be emitted in the non-gaseous form (e.g., particulate matter). To assess the effectiveness of

PM emission reduction techniques for Hg, As and Se an approximation of the partitioning for these elements over gas to solid phase needs to be made.

3.5.1 Mercury

Most of the atmospheric mercury is present as a gas either in the elemental state or in organic compounds (e.g. Schroeder and Munthe, 1998; Lee et al., 1998; Ames et al., 1998). Pacyna et al. (2001) reported for the European domain in 1995 that the emissions of gaseous elemental mercury contributed about 61% to the emissions of the total mercury, while the contribution of gaseous bivalent mercury and particulate mercury was 32 and 7%. In January 2005 the European Commission adopted an EU strategy on mercury. A position paper preceding the Hg strategy presented the rounded-off version of the Pacyna et al. estimate for the chemical speciation of Hg emission: 60% of anthropogenic emissions of mercury in Europe is estimated to be in a gaseous elemental form, 30% as gaseous bivalent mercury and 10% as elemental mercury on particles (EC, 2001a). Information on chemical speciation of mercury by source category is provided in Table 6.

Table 6 Emission profiles of Hg for major anthropogenic source categories in Europe in 1995 (in portion of the total) (Pacyna et al. 2001).

Species	Coal combustion				Nonferrous metals					
	Power plants	Residential Heat	Oil combustion	Cement production	Lead	Zinc	Pig & iron	Caustic soda	Waste incineration	Other
Hg^0 (gas)	0.5	0.5	0.5	0.8	0.8	0.8	0.8	0.7	0.2	0.8
Hg^{2+}	0.4	0.4	0.4	0.15	0.15	0.15	0.15	0.3	0.6	0.15
Hg (particulate)	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0	0.2	0.05

The partitioning factor for residential coal combustion in Table 6 may underestimate the contribution of particulate Hg. Hlawiczka et al. (2003) reported measurements in Polen where only 52% of the Hg emissions were in gaseous form. This would indicate that particulate removal would be more efficient for Hg than suggested by Table 6. Furthermore, although only 5-20 % of the Hg emissions are in particulate form the efficiency of the removal techniques may be higher because the gaseous emissions are either attached to particles or removed by washing / scrubbing of the exhaust gases (Table 7). However, as we did not know the exact state of technology for all UNECE countries we have followed the general partitioning for Hg as presented in the EU position paper, which states that only 10% is in particulate form. Future emission inventories e.g., dedicated to Hg only may improve our estimates using more detailed data such as presented in Table 7.

Table 7 Mercury removal efficiency and Cost-effectiveness of mercury control measures in utility boilers and waste incinerators (EC, 2001a).

Control Option	Mercury Removal Efficiency %	Costs	
		Investment	Operating and Maintenance
1. Power plant *1			
- ESPs (only)	10	1.6	0.2
- FFs (only	29	28.9	5.8
- ESP or FF + wet FGD	85	59.0	2.5
- dry absorber SDA+ESP	67	143.0	5.0
- ESP + carbon filter beds	90-95	264.0	62.0
- activated carbon injection +FF	50-90+	34.6	8.1
2. Municipal Waste Combustor (MWC) *2			
- ESP and FFs			
- as above			
- ESP or FF + carbon filter beds	99	31.7/80.0	6.5/15.6
- activated carbon injection + ESP or FF	50-90+	0.3/0.8	0.25/1.3
- polishing wet scrubber +ESP or FF	85	10.3/22.9	1.9/4.9
3. Medical Waste Incinerators (MWI) *2			
- ESP and FFs			
- as in p. 1.			
- activated carbon injection +FFs	50-90+	56.5/127.0	89.0/84.0
- polishing wet scrubber +FFs	85	400.0	100.0

*1 Investment cost in 1000 US$/MWh, while operating and maintenance cost in 1000 US$/MWh * year

*2 Investment cost in 1000 US$/tonne of waste, operating and maintenance cost in 1000 US$/1 tonne waste * year. Two estimates are given for large plant/small plant

3.5.2 Arsenic

Arsenic is mainly present in the fine particulate phase, but it can also form organic gaseous species when burnt (Léonard, 1991). Traces of arsenic, cadmium and nickel are found in fossil fuels like lignite (brown coal), hard coal and heating oil. Emissions of heavy metals are only relevant for those fuels burning with a considerable ash residue. Therefore, the combustion of natural gas and extra light heating oil is not a significant source for emissions of As, Cd and Ni (dust content < 0.1 mg/m^3). In the flue gas the heavy metals considered normally occur as compounds (e.g. oxides, chlorides) condensed on the surface of particles. Only arsenic is supposed to be emitted to a small extent in the vapour phase (EC, 2000a) This fraction can be calculated as 0.5 % (wt) from the arsenic content in the coal [Van der Most and Veldt, 1992].

3.5.3 Selenium

Relatively little is known about Selenium. According to Nriagu and Pacyna (1988) about 40% of Se is emitted in the volatile phase. However the Emission Factors Manual PARCOM-ATMOS (Van der Most and Veldt, 1992) suggest only 15% of

Se to be emitted in the gaseous phase. Since the latter was published later we assumed it integrated more data however, the information on selenium volatility is uncertain and considered (too) limited.

As discussed in this section, the heavy metals As, Hg and Se are partly emitted in a gaseous form, due to their physical properties. The fraction of As, Hg and Se assumed to be emitted in gaseous form is summarized in Table 8. This fraction is assumed not to be abated by PM emission reduction measures.

Table 8 Summary of fraction emitted in the gaseous form for the heavy metals As, Hg and Se.

Substance	Assumed percentage emitted in the gaseous form (%)	Prime reference
As	0.5	Van der Most and Veldt (1992)
Hg	90	EC (2001a)
Se	15	Van der Most and Veldt (1992)

3.6 Quantification of HM reduction due to dust reduction measures

3.6.1 Particulate matter concentrations in UNECE Europe

In the year 2000 (the reference year of this emission inventory) not all countries in UNECE Europe met the emission limit values for particulate matter of the HM Protocol. Therefore, in some countries more effective emission control measures will have to be implemented in order to meet the HM Protocol. We have investigated the sectors that are addressed by the Protocol, seeking representative stack concentrations of particulate matter as they were in the year 2000. This has been done based on the results and background information from the CEPMEIP Project (Visschedijk et al. 2004). The CEPMEIP project is a PAN European emission inventory of size differentiated primary particulate matter emission that is partly based on actual concentration measurement data from most European countries.. Particulate matter emission values differ significantly between countries. To take this into account, the UNECE countries have been divided in four abatement level groups as distinguished by Visschedijk et al. (2004). Each group represents a specific level of emission abatement as is (assumed) common practice in a member of the group in the year 2000. Group 1 represents the highest level of abatement whereas group 4 the lowest. The UNECE countries have been assigned to an abatement level group based on country specific information (Table 9).

Table 9 Allocation of countries to PM abatement level groups as defined in the CEPMEIP project (Visschedijk et al., 2004).

Group 1[a)]	Group 2	Group 3	Group 4
Austria	Belgium	Czech Republic	Albania
Switzerland	Cyprus	Estonia	Armenia
Germany	Spain	Hungary	Azerbaijan
Denmark	France	Lithuania	Bulgaria
Finland	United Kingdom	Latvia	Bosnia-Herzegovina
Iceland	Greece	Former Yugoslav Republic of Macedonia	Belarus
Luxembourg	Ireland	Poland	Georgia
Netherlands	Italy	Slovak Republic	Croatia
Norway	Portugal	Slovenia	Kazakhstan
Sweden			Kyrgyzstan
			Republic of Moldova
			Romania
			Russia
			Turkey
			Ukraine
			Federal Republic of Yugoslavia

[a)] Decreasing technology / abatement level going from group 1 to 4

An overview of the assumed total suspended particles (TSP) concentration by increasing emission abatement level and the limit values from the HM Protocol are presented in Table 10. The first column lists the sectors for which the Protocol sets limit values, the second to fifth column presents estimates for the concentration of particulate matter (after gas cleaning). Ruling particulate matter concentrations are given per abatement level group ID, as mentioned above. The sixth and seventh column list the current emission limit values of the HM Protocol. Table 10 reveals that the countries in group 1 appear to meet the Protocol limit values already. For the groups 2 to 4 additional measures appear to be needed since emissions / concentrations may be above the limit values.

Table 10 TSP concentration in main stack in Europe in the year 2000 by technology level, and emission limit values for the HM Protocol.

	TSP concentration in main stack (average and range, mg/Nm3)				HM protocol	
	Abatement level				Limit value I (mg/Nm3)	Limit value II
Category	1	2	3	4		
Power generation, coal-fired	20 (10 - 50)	100 (20 - 200)	400 (50 - 1000)	1500 (50 - 2000)	50	
Power generation, heavy oil-fired	75 (50 - 200)	100 (50 - 300)		150 (50 - 400)	50	
Industrial combustion >50MWth, coal-fired	50 (10 - 100)	300 (50 - 5000)		2000 (500 - 5000)	50	
Industrial combustion >50MWth, heavy oil-fired	75 (50 - 200)	100 (50 - 300)		150 (50 - 400)	50	
Industrial combustion >50MWth, wood-fired	200 (100 - 1000)				50	
Sinter plants (including non-ferrous metal sintering)	40 (20 - 300)	150 (75 - 300)		300 (75 - 1000)	50	
Pellet plants	100		N/A		25	
Blast furnaces	20 (5 - 50)		50 (20 - 80)	100 (20 - 200)	50	
Electric arc furnaces	20 (10 - 50)		50 (50 - 100)		20	
Primary copper production (thermal process)	10 (1 - 20)	80 (20 - 200)		200 (30 - 600)	20	
Secondary copper production (thermal process)	10 (5 - 20)	30 (10 - 200)		50 (20 - 200)	20	
Primary zinc production (thermal process)	20 (10 - 50)	50 (20 - 300)		200 (50 - 600)	20	
Secondary zinc production (thermal process)					20	
Primary lead production	3 (1 - 10)	15 (5 - 50)		50 (20 - 100)	10	
Secondary lead production	6 (1 - 10)	25 (5 - 50)		50 (20 - 100)	10	
Other non-ferrous metals: primary nickel	N/A			500 (100 - 1000)	General limit value	
Production of cement	40 (20 - 100)	50 (30 - 100)		400 (100 - 800)	50	
Glass production using lead in process	50 (2 - 80)	100 (80 - 300)		150 (100 - 500)	5**	
Chlor-alkali industry	0,01 (0 - 0.02)*	2 (1 - 5)*		10 (1 - 20)*	0.01*	
Municipal waste incineration	10 (5 - 50)	80 (50 - 200)		100 (40 - 400)	25	0.08***
Hazardous waste incineration	10 (5 - 50)	80 (50 - 200)		100 (40 - 400)	10	0.05***
Medical waste incineration	20 (10 - 50)	100 (50 - 200)		200 (50 - 400)	10	0.05***
Industrial waste incineration	20 (10 - 50)	100 (50 - 200)		200 (50 - 400)	25	0.08***

* Unit: g Hg/Mg Cl2
** Unit: mg Pb/Nm3
*** Unit: mg Hg/Nm3

3.6.2 Calculation of the reduction of heavy metals resulting from particulate matter limit values

In case the year 2000 concentration is higher than the Protocol value, the 2000 concentration will have to be reduced with to a certain degree. The reduction fraction for particulate matter (PM) serves as the basis on which the subsequent heavy metal (HM) reduction is estimated, since HM are primarily particle-bound. However, the HM reduction fraction is not equal to the reduction in PM concentration because of a phenomenon called 'Enrichment'. This means that HM are preferentially found in the smaller size fractions of PM. Based on literature data, we have estimated the degree of enrichment of the smaller sized particles by the individual HM species covered by this study. The results are relative HM concentrations by particle size class (Table 11).

Table 11 Enrichment factors for HM in particulate matter fractions used in the present study.

Pollutant	PM2.5	PM2.5-10	PM>10	Total
Cd	0.8	0.1	0.1	100%
Pb	0.8	0.1	0.1	100%
Hg	0.08	0.01	0.01	10%
As	0.796	0.0995	0.0995	99.5%
Cr	0.3	0.2	0.5	100%
Cu	0.65	0.05	0.3	100%
Ni	0.54	0.23	0.23	100%
Se	0.68	0.09	0.09	86%
Zn	0.8	0.07	0.13	100%

Compilation based on van der Most and Veldt (1992); Linak et al. (2000) and Yoo et al. (2002)

Based on the CEPMEIP project (Visschedijk et al. 2004), the information from Table 10 has been extended with particulate matter size distribution data. The fraction PM10 and PM2.5 of TSP is strongly dependant on the applied PM emission control. Therefore, for each individual data entry in Table 10, a representative PM10 and PM2.5 fraction has been estimated (Table 12).

Table 12 Particle size distributions (PM10 and PM2.5 fractions) in Europe in 2000 by technology level, and estimated size fractions after implementation of the HM Protocol.

Category	PM10 fraction (-)				PM2.5 fraction (-)			
	Abatement level				Abatement level			
	1	2	3	4	1	2	3	4
Power generation, coal-fired	0.95	0.73	0.5	0.35	0.75	0.35	0.12	0.08
Power generation, heavy oil-fired	1	0.63		0.2	0.83	0.35		0.06
Industrial combustion >50MWth, coal-fired	0.7	0.6		0.5	0.3	0.35		0.2
Industrial combustion >50MWth, heavy oil-fired	0.86	0.8		0.8	0.72	0.7		0.54
Industrial combustion >50MWth, wood-fired	0.6				0.35			
Sinter plants (including non-ferrous metal sintering)	0.5	0.5		0.4	0.5	0.42		0.25
Pellet plants	1		N/A		1		N/A	
Blast furnaces	0.95		0.8	0.5	0.9		0.5	0.25
Electric arc furnaces	0.9		0.8		0.55		0.35	
Primary copper production (thermal process)	0.95	0.8		0.3	0.8	0.6		0.1
Secondary copper production (thermal process)	0.8				0.6			
Primary zinc production (thermal process)	0.9	0.8		0.8	0.8	0.6		0.6
Secondary zinc production (thermal process)	0.8				0.6			
Primary lead production	0.95	0.8		0.3	0.5	0.4		0.06
Secondary lead production	0.95	0.8		0.7	0.5	0.4		0.4
Other non-ferrous metals: primary nickel	N/A			0.6	N/A			0.3
Production of cement	0.9	0.85		0.4	0.4	0.3		0.15
Glass production using lead in process	0.9				0.8			
Chlor-alkali industry	N/A				N/A			
Municipal waste incineration	1	0.7*			1	0.4*		
Hazardous waste incineration								
Medical waste incineration								
Industrial waste incineration								

* Estimated; not in CEPMEIP

The effect of particulate matter reduction on the emission of a certain HM can be calculated knowing how the HM is partitioned over the different size ranges of PM (Table 11) and how much of the HM is in the particulate phase (Table 8). The first step is to calculate the PM mass reduction by particle size class (PM>10, PM2.5-10 and PM2.5) given a certain overall PM reduction fraction and size distribution data before and after PM abatement has taken place (Table 10, Table 12). Next, the subsequent HM reduction can be calculated by PM size class using the enrichment data from Table 11. Summation of all size classes results in the overall HM reduction for a specific measure, country and sector. This is the way in which HM reduction as a result of the implementation of the HM Protocol has been estimated for particle-bound HM emission. In specific cases (like for Hg from chloro-alkali plants) a limit value refers not to dust but directly to a specific metal. The relative

HM emission reduction can in those cases be calculated by comparing the emission or concentration data before and after emission control.

A similar approach has been followed in order to estimate the HM emission reduction as a result of the autonomous measures listed in section 3.4. Table 13 presents the data needed to calculate the HM emission reduction fractions due to implementation of planned autonomous policy as described earlier.

Table 13 TSP concentrations and particle size distributions in Europe after implementation of various autonomous emission control measures (section 3.4)..

Category	TSP concentration (mg/Nm^3)				PM10 fraction (-)				PM2.5 fraction (-)			
	policy measure				policy measure				policy measure			
	IPPC BAT	LCP Dir.	MSW Dir.	2nd S Prot.	IPPC BAT	LCP Dir.	MSW Dir.	2nd S Prot.	IPPC BAT	LCP Dir.	MSW Dir.	2nd S Prot.
Power generation, coal-fired	20	50	N/A	30	0.95	0.85	N/A	0.93	0.75	0.65	N/A	0.7
Power generation, heavy oil-fired	40	50	N/A	40	1	1	N/A	1	0.9	0.85	N/A	0.9
Industrial combustion >50MWth, coal-fired	30	50	N/A	80	0.9	0.8	N/A	0.65	0.4	0.5	N/A	0.45
Industrial combustion >50MWth, heavy oil-fired	40	50	N/A	40	1	0.9	N/A	1	0.78	0.75	N/A	0.78
Industrial combustion >50MWth, wood-fired	50	50	N/A	N/A	1	1	N/A	N/A	0.8	0.8	N/A	N/A
Sinter plants (including non-ferrous metal sintering)	40	N/A	N/A	N/A	0.7	N/A	N/A	N/A	0.5	N/A	N/A	N/A
Pellet plants	25	N/A	N/A	N/A	1	N/A	N/A	N/A	1	N/A	N/A	N/A
Blast furnaces	20	N/A	N/A	N/A	0.95	N/A	N/A	N/A	0.9	N/A	N/A	N/A
Electric arc furnaces	20	N/A	N/A	N/A	0.9	N/A	N/A	N/A	0.55	N/A	N/A	N/A
Primary copper production (thermal process)	10	N/A	N/A	80	0.95	N/A	N/A	0.8	0.8	N/A	N/A	0.6
Secondary copper production (thermal process)	10	N/A	N/A	N/A	0.8	N/A	N/A	N/A	0.6	N/A	N/A	N/A
Primary zinc production (thermal process)	20	N/A	N/A	80	0.9	N/A	N/A	0.8	0.8	N/A	N/A	0.6
Secondary zinc production (thermal process)	20	N/A	N/A	N/A	0.8	N/A	N/A	N/A	0.6	N/A	N/A	N/A
Primary lead production	10	N/A	N/A	N/A	0.95	N/A	N/A	N/A	0.5	N/A	N/A	N/A
Secondary lead production	10	N/A	N/A	N/A	0.95	N/A	N/A	N/A	0.5	N/A	N/A	N/A
Other non-ferrous metals: primary nickel	20	N/A	N/A	80	0.9	N/A	N/A	0.8	0.6	N/A	N/A	0.5
Production of cement	30	N/A	30	N/A	0.95	N/A	0.95	N/A	0.45	N/A	0.45	N/A
Glass production using lead in process	20	N/A	N/A	N/A	0.95	N/A	N/A	N/A	0.8	N/A	N/A	N/A
Chlor-alkali industry	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Municipal waste incineration	10	N/A	10	N/A	1	N/A	1	N/A	0.9	N/A	0.9	N/A
Hazardous waste incineration	10	N/A	10	N/A	1	N/A	1	N/A	0.9	N/A	0.9	N/A
Medical waste incineration	10	N/A	10	N/A	1	N/A	1	N/A	0.9	N/A	0.9	N/A
Industrial waste incineration	10	N/A	10	N/A	1	N/A	1	N/A	0.9	N/A	0.9	N/A

3.7 Scenario data; basis for projection of source activity data

For an accurate emission projection it is important to consider the expected developments of source activity rates. Therefore scenario data are incorporated to estimate e.g., future energy consumptions and fuel types, industrial and agricultural production. There are several types of scenario data to be used for projecting activity rates for the target years and the relevant source types:
- Energy use and fuel type shares (stationary sources)
- Physical industrial production (stationary sources, industrial product use)
- Population growth and GDP development related (product use by consumers)
- Agricultural production (pesticide use)
- Waste generation and disposal type

The projection of activity data is as much as possible based on and in line with the baseline scenarios developed by International Institute for Applied Systems Analysis (IIASA) in the framework of the Clean Air for Europe (CAFE) program (Amann et al., 2005). The Economic activities relevant for air emissions are divided into the following categories: Energy, Process, Agriculture, Mobile. For further details and the data of the CAFE baseline scenario we refer to Amann et al. (2005) and the web-version of the RAINS model (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/)

For some source sectors that are important for HM emissions, no projections are made in the framework of the CAFE programme (Amann et al., 2005). For these sectors (e.g. waste incineration) a projection to 2010, 2015 and 2020 was made by TNO (section 3.7.2).

3.7.1 Energy activities

Energy combustion is the major economic activity responsible for emissions of air pollutants. Scenarios of energy use by individual countries/regions are called energy (activity) pathways. They describe the sectoral use of different fuel types over time. Two energy pathways defined by IIASA could be used to project the year 2000 activities to the years 2010, 2015 and 2020.

I. Baseline energy pathway without climate policies: ***BL_CLE_Apr04 (Aug04):***
- Control strategy: Current legislation.
- Version of activity pathway/ control strategy: April 2004.
- Version of emission vector: August 2004.
- Uses "Energy and Transport - Trends to 2030" of DG Transport and Energy and Europe-wide consistent projections of agricultural activities without CAP reform.

II. Climate policy energy pathway: ***CP_CLE_Apr04 (Aug04):***
- Control strategy: Current legislation.
- Version of activity pathway/ control strategy: April 2004.
- Version of emission vector: August 2004.
- Energy projection "with climate measures" developed with the PRIMES model.

In the present study we apply option I, the baseline energy pathway without climate policies, as this is likely to be the more “conservative” scenario. However, to investigate the sensitivity of the HM projections for the choice of energy pathway, HM emissions projections are also made for option II. The results are discussed in section 5.2.1.

3.7.2 Activity scenarios not included in the CAFE baseline scenarios

Not all activities that are important for estimating HM emissions can be projected using the CAFE baseline scenarios (Amann et al., 2005). For several activities assumptions to derive a projection for activities had to be made. The most important are listed below.
- The scenario for Lead emission from road transport (CRFSubID 139, annex 3) has been determined using the European strategy to phase out leaded petrol (UNECE, 1998).
- The European Topic Centre Waste did not yet have projection data for waste incineration available (pers comm. ETC Waste, May 2005). A scenario for municipal waste incineration (CRFSubID 135, annex 3) is made by TNO based on an EC waste management options study (AEA Technology, 2001).
- For other remaining activities that are coupled to population size (e.g., use of products), scenario data have been used from the same source as the population data for 2000 (CIESIN, 2001). We created scaling factors or indexes to scale the emissions in 2000 to 2010, 2015 and 2020.

Some additional conservative assumptions needed to be made to allow calculation of projected emissions. This only applied for a limited number of activities which only account for a small fraction of the emissions:
- No change in agricultural production data: The ‘common format’ AGR has been put on 1 as has been done with the Fungicide use (CRFSubID 147). This has been done due to a lack of appropriate data for these activities.
- When the CAFE scenario made by Amann et al. (2005) gives an activity value of “0” for a specific fuel use in a specific activity in the year 2000, a scaling index could not be calculated. In these occasions we used a constant scenario index of 1 for all years.
- For all remaining activities where no projection data could be derived (“rest-posten”), a scenario index of 1 for all years has been used.

3.8 Spatial Resolution of the emission data

For the distribution of national country emission totals over the EMEP 50 x 50 km^2 grid, both point source information, population density and land use data have been used. Point source information has been applied for the distribution of emissions from the energy transformation sector (including refineries), the industrial combustion (only larger plants ~ > 50 MWth), the iron and steel industry, the non-ferrous metal industry, the cement industry (for central and eastern Europe), petrochemical industry and municipal waste incineration (for Western Europe. All other categories are distributed using the population density distribution (CIESIN, 2001). To distribute the sector totals over point source locations both the location and the on-site production or fuel consumption data have been used. When the actual production or fuel consumption data of a specific point source was not available it has been allocated a production related to the known capacity of that site and to the total country production. E.g. when the total country production is 80% of the total country capacity, a site is allocated an assumed production rate of 80% of its capacity. The gridding of data is a semi-automatic process at TNO. A more detailed description of the gridding methodologies is provided by Visschedijk and Denier van der Gon (2005).

4. The official country emissions data base

Parties to the Convention on LRTAP submit total annual emission values for pollutants including HM to the UNECE secretariat. According to the MSC-E Technical Report 5/2003 (Ilyin and Travnikov, 2003), 34 countries submitted HM data of which 16 country submissions were complete in time and substance coverage. The present study makes an emission inventory for Heavy Metals for year 2000 based on submissions of emission data from the Parties to the Convention complemented by TNO default estimates to achieve completeness. The explicit aim is to incorporate as much country data as possible (country data meaning emission data prepared by national experts of that country). To achieve this goal two separate databases are developed and/or used. The first database is a bottom-up TNO inventory as described in chapter 3; the TNO reference emission database for the year 2000. The second database consists of the official reported EMEP data, the so-called "Official" database. In this chapter the origin and coverage of officially submitted emission data is described and the subsequent integration (merging) of the official database and reference database into the final merged database is described.

4.1 Collection of country data

The starting point for the official database is the database which was kindly made available by the European Topic Centre on Air and Climate Change (ETC-ACC, 2003) containing official submitted data. In essence this is the same database as the official EMEP database (UNECE/EMEP, 2004), but the difference is that the ETC database is updated several times a year whereas a new version of the official EMEP database is uploaded once a year. Several steps and additions are necessary to get a unique (no double counting) and complete database. Therefore, the database has been supplemented with information based on the former TNO assessment (Berdowski et al, 1997a), resulting in a first version of the official database. The data quality is further improved by checks and communication with country experts (see section 2.1) and cross-checking with the UNECE/EMEP emission database as available through the WebDab tool (http://webdab.emep.int/). In the present study only official data which have a split at the sector level (e.g. NFR level 1 or SNAP level 1) can be used because otherwise no indication of completeness of the inventory can be obtained. An overview of the official HM emission data that meet this criterion is provided in Table 14. TNO processed all the submitted information in a uniform Common Format code (Table 4), so that the different countries' submissions could be compared and aggregated. First the deadline for official emission data was set at May 15, 2004. It was later decided to process all country data submitted before 1 March 2005 as major improvements were still received after the first deadline and the aim of the project is to keep maximum compatibility with the official data and insights of the countries.

Table 14 Overview of available official emission data by substance.

	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
	(kg / year)								
ALB									
ARM									
AUT		1427			1151		13853		
AZE									
BEL	3840	2750	24950	26850	2260	52690	133800	4320	166330
BGR		10986			4186		213359		
BIH									
BLR	3330	1378	6295	11778	358	94430	46121		196486
CHE		2176			2630		113569		558287
CYP							73162		
CZE		2840			3840		107710		
DEU									
DNK	845	729	2409	9072	2052	13731	7514	2017	22182
ESP	56072	18081	45483	216011	21788	265662	634786	60758	1947555
EST	9668	680	9686	3482	553	7865	40730	6	52963
FIN	4500	1400	28000	18700	500	33200	37500		70600
FRA	25264	10453	259392	177165	13375	221679	234098	14262	1441441
GBR	38022	7249	69354	48183	8793	125288	192842	28849	413184
GEO									
GRC									
HRV	1068	1019	4312	9788	409	26550	146907	633	61059
HUN	5709	2746	6657	15229	4196	37235	36954	1620	40146
IRL									
ISL									
ITA	43573	11111	46594	58506	10146	166716	920312	92307	1432364
KAZ									
KGZ									
LTU	782	1351	2310	6398	252	26562	15917		61814
LUX	79	51	342	1252	275	680		24	36697
LVA	624	589	5731	4095	148	11006	8230	427	56498
MDA	477	373	626	1573	146	5859	3167	54	907
MKD		167			48		3020		
NLD	1258	1158	5558	15537	578	53161	44070	122	103445
NOR	2457	725	8814	19329	996		6035		
POL	50400	50400	84300	374500	25600	251600	647500		2173000
PRT									
ROM									
RUS		50500			10000		2352000		
SVK	11219	7248	8059	23685	4371	23572	74343	7075	59190
SVN		1540			580		37150		
SWE	594	425	6462	15116	746	17715	11811	569	92328
TUR									
UKR									
YUG									

4.2 Processing of country data

A complication in making the so-called official database is that the official data are submitted by the countries in three different reporting formats (EMEP SNAP97, CLRTAP NFR old sectors, CLRTAP NFR new sectors). None of the three formats covers the entire range of submissions (see also http://webdab.emep.int/). When several formats were available for one country, the (latest) data of only one reporting format is used. Whenever possible NFR new was selected as this is likely to be the future reporting format. However, in some occasions this proofed difficult, since the country totals of the different reporting formats did not always correspond. As already indicated in section 4.1, official country emissions that are available as a national total only, could not be used in our approach because it is than impossible to attribute (disaggregate) the national total emission to source sectors. This is essential to check if all relevant source sectors are covered which gives a good impression of the completeness of a country's inventory. In cases where not all relevant source sectors are covered but data are submitted for some sectors, the official submitted data can be used and complemented by TNO reference estimates for the missing source sectors. The aggregated national total emission will than consist of partly official submitted data and partly expert estimates. It is important to note that in such cases the aggregated national total as available from EMEP will be lower than the aggregated national total in this study.

The official emission data were compared with the TNO estimates for each country to identify major differences between the TNO estimates and the official emission data. Differences were considered to be significant when the country estimate differed more than a factor of three from the TNO estimate and the source considered did contribute more than 10% to the national total (either as submitted by the country or as estimated by TNO). In these cases, TNO tried to elucidate the causes of the discrepancies which could be e.g., different activity data or country-specific emission factors.

To compare the data in the official database with the TNO reference database data, the data are aggregated at the level of a defined "Common Format" (Table 4). It was necessary to create a new "common format" in this study because the official emission data are retrieved from mixed formats, as discussed above. The common format allows bottom up aggregation of both official database and the reference database. Annex 3 lists the considered emission sources in this study and the translation from official reporting formats to the Common Format. Next, the two independent databases can be compared at the level of the Common Format (Table 4).

4.3 Merging of official emission data and expert estimates

To create a final dataset the official emission values have been merged with the reference emission inventory to get complete coverage of all countries and all sec-

tors in the UNECE-Europe region. Starting point of the new merged database are the data from the official database. All validated country data overrule the TNO estimates that are in the reference database, the source sector estimates in the TNO reference database only fill in the “gaps”.
Official emission data are only discarded and replace by TNO reference data in a few rare cases when:

1. the difference between official and expert estimates could not be understood and,
2. the source in question contributed significantly to the total emissions of the particular substance (> 10%) and,
3. the choice for official emission data would alter the regional emission pattern and outcome of the key source analysis.

However, the origin of the emission data can still be seen in Annex 4 and at the common format level in annex 6. Official emission data are printed black, TNO expert estimates are presented in blue italics.
Before the final merged database can be used for projections, the inventory has to be scaled. All emissions in the Common Format will be scaled to activities and fuels from the reference inventory. These activities and fuels can than be scaled to 2010, 2015 and 2020 using the scenario data described in section 0.
It is important to note that the projected data are only created using indexes for the year 2000 emissions. This is crucial to get a consistent outcome because the starting point are official emission data but exact activity data as used by the countries cannot be traced. Hence, a separate bottom-up approach for 2010-2020 could result in unexplainable “jumps” in HM emissions.
Furthermore, since the merged data base is truly merged and no longer a bottom up “process” correction of errors or implementation of additional submitted data especially in the official database lead to a rather time-consuming process of re-doing the merging.

4.3.1 Spatial distribution of the merged data base

When only total country emission per main Common Format is known, the subdivision from TNO reference estimates is used to subdivide those emissions into subcodes (CRFsubIDs, Annex 3). Whenever countries were not in a position to deliver data for one or more source categories, they were asked to comment on the TNO default data for their country and, if possible to present alternative values. Per source category national totals have been distributed over point sources according to production or capacity of the site (as in the TNO database). When the country did not supply any point source information, data collected by TNO have been used.

5. Results and Discussion

In this chapter the overall results for UNECE Europe and several groups of countries are presented. The HM emissions by source category for each individual country in the year 2000 are presented in annex 4, a more detailed breakdown of the annual HM emissions by country per source category and fuel is available on CD-ROM inserted in the back cover. The spatial distribution of HM emissions over Europe on the EMEP 50 x 50 km^2 grid is presented in annex 5. In the following section the results are presented and discussed for UNECE-Europe and for selected country groups.

5.1 Heavy metal emissions in UNECE-Europe for the year 2000

The calculated emissions for the year 2000 are presented in Table 15. For a description of the sectors see Table 4. Two source sectors, solvent and product use (4_SPU) and agriculture (8_AGR) do not have any HM emissions in the TNO reference database. However, a few countries do report emissions for these sectors (Table 15). The data for these source sectors are presented on one significant digit (e.g. 0.04 is presented in stead of 0) to illustrate that the official reported emissions are conserved in the merging process (see section 4.3). However, as can be seen from Table 15, the sectors solvent and product use and agriculture are unimportant and the allocation of emissions to these sectors is questionable as they may originate from errors in following the reporting methodology. For example according to the reporting definitions, emissions due to fuel use in agricultural machinery are to be reported under non-road transport and not under agriculture. In emission tables presented further in this report all emissions are rounded to tonnes / yr with no decimal digits. The source sectors solvent and product use and agriculture may be missing from tables and graphs further in this report because their contribution is negligible. Although the emissions by country (Annex 4, Annex 6) present the emissions in kg/yr, the accuracy is at most two significant digits. Nevertheless, in Annex 4 and Annex 6 the complete figures are represented because this may facilitate discussion and cross-checking of the origin of data.

Table 15 Annual emissions of heavy metals in UNECE-Europe per source category for year 2000.

Source sector	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
	Tonnes/yr								
1_PHP	176	99	177	454	133	1491	1547	108	3943
2_RCO	57	49	121	278	29	410	390	17	1458
3_IND	318	214	2005	1287	142	2130	4466	371	12355
4_SPU	-	-	-	-	0.04	-	0.02	-	-
5_ROT	0.4	5.5	19	460	0.1	34	8329	3.0	1051
6_NRT	1.5	0.7	1.5	327	0.3	62	154	1.6	23
7_WAS	2.3	8.6	27	40	39	15	134	0.7	674
8_AGR	-	-	-	0.1	-	0.2	0.1	-	-
Grand Total	555	377	2350	2846	344	4144	15021	501	19503

The source categories considered in the present inventory are listed in Annex 3. The major contributing source categories to total UNECE European emissions by compound for heavy metals are:

- **Cd**: Mainly due to combustion of Hard and Brown Coal and Heavy Fuel Oil in Heat/Power Plants, Primary Zinc and Copper Production and the Iron and Steel Industry (especially Sinter Production).
- **Hg**: Mainly due to the combustion of Hard and Brown Coal in Heat/Power Plants and Industry. Also Cement Production is a very important source (>50% of 3_IND).
- **Pb**: Combustion in Road Transport is by far the most important source. Furthermore Hard Coal combustion in Heat/Power Plants and Iron & Steel industry (Sinter Production and Blast Furnaces) should be mentioned.
- As: Mainly due to combustion of Hard and Brown Coal in Heat/Power Plants and Hard Coal and Heavy Fuel Oil in Industry. Besides that, Primary Copper Production and I&S Blast Furnaces are important sources.
- Cr: Primary Nickel Production is responsible for more than 60% of the emissions.
- Cu: A variety of sources is responsible. Most imported is the Primary Copper Production, shortly followed by Hard Coal Production in Heat/Power Plants and Rail Transport. But also Diesel and Gasoline combustion in Road Transport and I&S Blast Furnaces are important sources.
- Ni: Mainly due to Heavy Fuel Oil combustion in Heat/Power Plants, Industry and Oil Refineries. Within the sector Industry also Primary Nickel Production is an important source.
- Se: Glass Production is the dominating source. Hard Coal combustion in Heat/Power Plants is less important.
- Zn: A number of sources are responsible for the majority of the emissions: Heat/Power Plants, Industry and Residential Hard Coal combustion, Blast Furnaces in the Iron & Steel industry, Electric Arc and Oxygen Furnaces and Primary Copper and Zinc Production.

5.2 Projected Heavy metal emissions in UNECE-Europe for 2010, 2015 and 2020

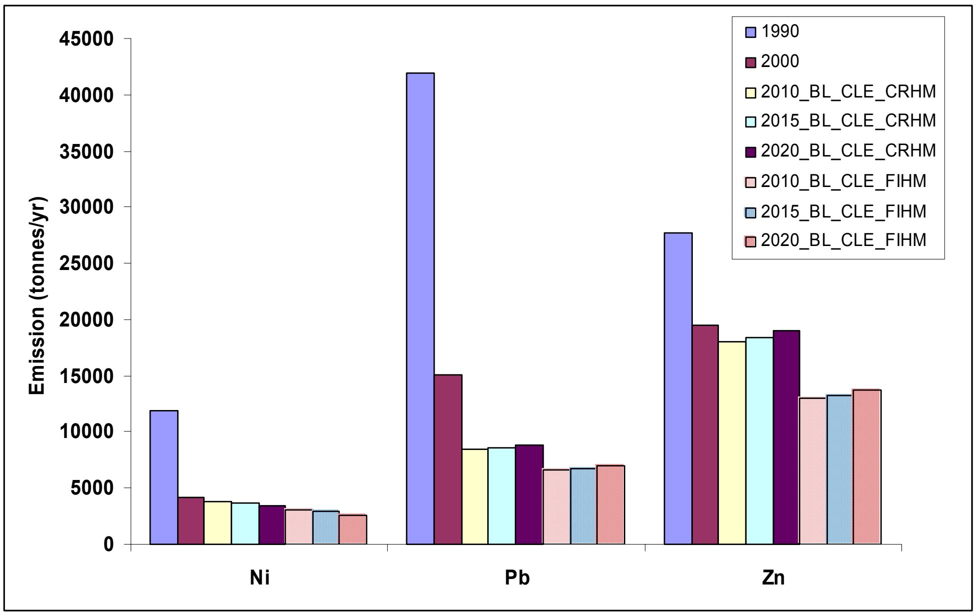
The HM emission database for the year 2000 has been projected to the years 2010, 2015, and 2020 following two policy scenarios **BL_CLE_CRHM** (Base Line scenario with Current Legislation and Current Ratification (as of April 2005) of HM Protocol) and **BL_CLE_FIHM** (Base Line scenario with Current Legislation and Full Implementation of HM Protocol) as described in section 3.3 (Table 16). The results shown in Table 16 are graphically depicted in Figure 2. To investigate emission trends data of the previous 1990 HM inventory (Berdowski et al., 1997a) are included in Table 16 and Figure 2 for indicative comparison. The 1990 and 2000 data are not fully comparable because of differences in estimation methodology and the possible retrospective adjustments in official country emission data. Furthermore, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, and Turkey are not inventoried by Berdowski et al. (1997a), but are included in the present study. To approximate the 1990 emission levels, these countries are represented by their year 2000 emissions in the total UNECE_Europe 1990 estimates of Table 16 and Figure 2. Therefore, the presented 1990 emissions are conservative estimates and may be underestimated. A more detailed comparison of 1990 and 2000 emissions is provided in section 5.6.

Table 16 Projected HM emissions in UNECE Europe for 2010, 2015 and 2020 following two policy scenarios.

Year_policy scenario	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
	Tonnes / yr								
1990[a)]	650	501	41879	1284	2289	6078	11930	NA[b)]	27659
2000	377	344	15021	555	2350	2846	4144	501	19503
2010_BL_CLE_CRHM	327	328	8455	449	2328	2642	3750	317	18025
2015_BL_CLE_CRHM	326	325	8578	444	2489	2698	3649	321	18369
2020_BL_CLE_CRHM	323	326	8835	438	2645	2772	3426	325	19006
2010_BL_CLE_FIHM	226	318	6566	332	884	2033	3063	285	12973
2015_BL_CLE_FIHM	222	315	6689	325	894	2070	2903	290	13218
2020_BL_CLE_FIHM	217	316	6946	318	900	2126	2622	294	13766

a) 1990 data taken from Berdowski et al. (1997a) for indicative comparison. Countries not covered by Berdowski et al. are represented by their year 2000 emissions

b) NA = Not Available.



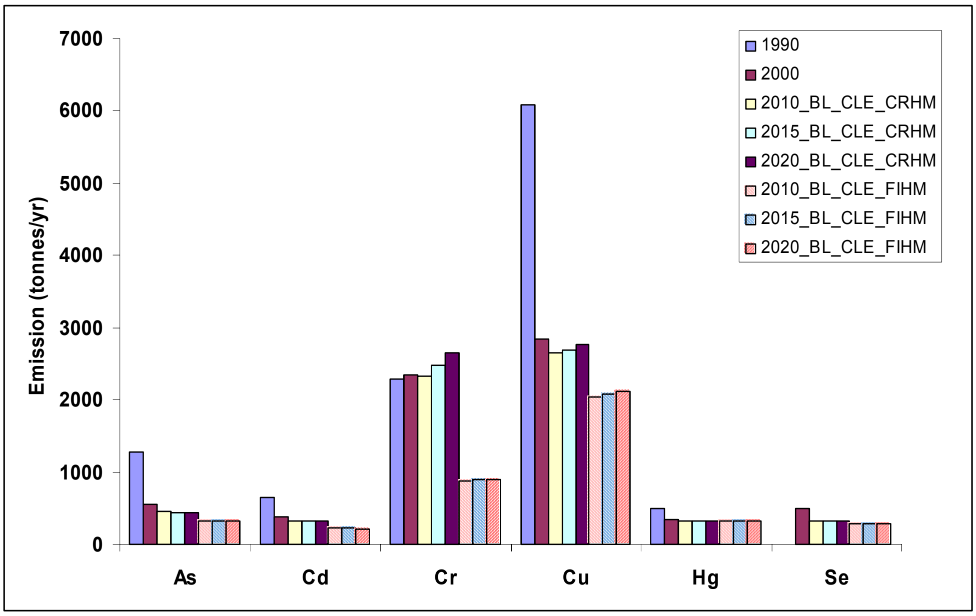


Figure 2 HM emissions in UNECE Europe for 2000 and projected emissions for 2010, 2015 and 2020 following two policy scenarios.

The emissions of Cd, Hg, Pb, As, Cu, Ni and Zn have been reduced with 42%, 31%, 64%, 57%, 53%, 65% and 29%, respectively over the period 1990-2000. Remarkably Chromium emissions are still estimated to be at the same level as 1990. Chromium emissions are only expected to significantly decrease if all countries implement the HM Protocol (Figure 2). However, Berdowski et al. (1997a) did not include Ni production as a major source of Cr. Hence the 1990 Cr emissions are probably underestimated. Since Berdowski et al. (1997a) did not provide 1990 data for selenium emissions, no reduction fraction could be calculated for Se.

Compared to the period 1990-2000, over the next decade (2000-2010) and current ratification a large emission reduction is only foreseen for Pb due to the phase out of leaded petrol. However, full implementation of the HM Protocol by all UNECE-Europe countries brings about considerable HM emission reductions. Important observations from the projected HM emissions in UNECE Europe for 2010, 2015 and 2020 following two policy scenarios based on Table 16 and Figure 2 are:

- For Pb, Se and As considerable reduction (20~40%) is achieved going from the year 2000 to 2010 following the baseline scenario and current ratification of the HM Protocol.
- The lead emissions strongly decline going from 2000 to 2010 due to the phase out of leaded gasoline. The remaining limit value of Pb in fuel however causes road transport to remain an important source of Pb.
- Emission of Cr is the only HM that is expected to grow in emission compared to 2000. This is due to activity increase in (Ni production) countries that have currently not ratified the protocol.
- If all countries of UNECE-Europe implement the HM Protocol the projected emissions are considerable reduced (20-60%) compare to the year 2000 for all HM except Hg. This is because Hg is mostly emitted in the gaseous phase and is poorly mitigated by the currently proposed measures. This is also the reason why Hg emission reduction over 1990-2000 has been smaller than for the other two priority HM.
- The difference in HM emissions under the two policy scenarios is larger than the emission changes over time within a policy scenario (e.g. going from 2010 to 2020).

The last conclusion illustrates that full implementation of the HM Protocol is an important step in HM emission reduction. The relative small importance of the projection years (2010-2015-2020) can be explained by 1) our assumption that measures following implementation of the HM Protocol will be in effect before 2010 (in both policy scenarios) and little additional measures are yet defined for the period after 2010.

To see more detail in the origin of the current emissions and the possibly remaining emissions following the two policy scenarios, the annual emissions of heavy metals in UNECE-Europe per source category in 2000, 2010, 2015 and 2020 are presented in Table 17 and Table 18.

Table 17 Annual emissions of heavy metals in UNECE-Europe per source category in 2000, 2010, 2015 and 2020 (tonnes per year). Projections for 2010-2020 are made following the IIASA CLE-BL scenario and assuming current (as of April 2005) ratification of HM Protocol and including foreseen autonomous measurements (BL_CLE_CRHM).

Source sector	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
		Tonnes/yr								
1_PHP	2000	176	99	177	454	133	1491	1547	108	3943
	2010	153	99	130	421	135	1371	1623	85	3892
	2015	148	96	124	411	132	1285	1585	81	3872
	2020	145	91	112	402	134	1123	1557	80	3992
2_RCO	2000	57	49	121	278	29	410	390	17	1458
	2010	43	41	108	236	29	330	320	13	1274
	2015	38	37	99	209	27	287	284	11	1142
	2020	34	34	90	186	25	252	252	10	1008
3_IND	2000	318	214	2005	1287	142	2130	4466	371	12355
	2010	250	173	2040	1027	146	1930	3499	213	10776
	2015	255	179	2214	1071	149	1953	3554	223	11127
	2020	255	184	2388	1127	150	1922	3693	229	11598
4_SPU	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
5_ROT	2000	0	6	19	460	0	34	8329	3	1051
	2010	0	8	25	566	0	46	2788	4	1432
	2015	0	8	28	611	0	52	2947	4	1577
	2020	0	9	31	661	0	57	3131	4	1757
6_NRT	2000	1	1	2	327	0	62	154	2	23
	2010	2	1	2	359	0	63	135	2	22
	2015	1	1	1	363	0	63	117	2	21
	2020	1	1	1	363	0	64	112	2	21
7_WAS	2000	2	9	27	40	39	15	134	1	674
	2010	2	5	23	33	17	8	90	1	629
	2015	2	5	23	33	17	8	90	1	630
	2020	2	5	23	33	17	8	91	1	631
8_AGR	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
Total	2000	555	377	2350	2846	344	4144	15021	501	19503
	2010	449	327	2328	2642	328	3750	8455	317	18025
	2015	444	326	2489	2698	325	3649	8578	321	18369
	2020	438	323	2645	2772	326	3426	8835	325	19006

Table 18 Projected annual emissions of heavy metals in UNECE-Europe per source category in 2000, 2010, 2015 and 2020 (tonnes per year). Projections for 2010-2020 are made following IIASA CLE-BL scenario and assuming all UNECE countries ratify the HM Protocol before 2010 (BL_CLE_FIHM).

Source sector	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
		Tonnes/yr								
1_PHP	2000	176	99	177	454	133	1491	1547	108	3943
	2010	73	45	93	120	129	1302	442	56	1155
	2015	70	43	87	116	125	1217	428	53	1187
	2020	69	39	76	113	127	1057	427	53	1366
2_RCO	2000	57	49	121	278	29	410	390	17	1458
	2010	43	41	108	236	29	330	320	13	1274
	2015	38	37	99	209	27	287	284	11	1142
	2020	34	34	90	186	25	252	252	10	1008
3_IND	2000	318	214	2005	1287	142	2130	4466	371	12355
	2010	212	126	634	719	144	1313	2800	210	8468
	2015	214	129	656	738	146	1276	2831	220	8669
	2020	211	129	679	771	146	1184	2943	225	8992
4_SPU	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
5_ROT	2000	0	6	19	460	0	34	8329	3	1051
	2010	0	8	25	566	0	46	2788	4	1432
	2015	0	8	28	611	0	52	2947	4	1577
	2020	0	9	31	661	0	57	3131	4	1757
6_NRT	2000	1	1	2	327	0	62	154	2	23
	2010	2	1	2	359	0	63	135	2	22
	2015	1	1	1	363	0	63	117	2	21
	2020	1	1	1	363	0	64	112	2	21
7_WAS	2000	2	9	27	40	39	15	134	1	674
	2010	2	5	23	32	16	8	81	1	622
	2015	2	5	23	32	16	8	81	1	622
	2020	2	5	23	32	16	8	81	1	622
8_AGR	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
Total	2000	555	377	2350	2846	344	4144	15021	501	19503
	2010	332	226	884	2033	318	3063	6566	285	12973
	2015	325	222	894	2070	315	2903	6689	290	13218
	2020	318	217	900	2126	316	2622	6946	294	13766

5.2.1 Choice of energy pathway

In section 3.7.1 the two energy pathways defined by IIASA (Amann et al. 2005) were introduced; The baseline energy pathway without climate policies: BL_CLE_Apr04 (Aug04): and the Climate policy energy pathway: CP_CLE_Apr04 (Aug04). To investigate the sensitivity of the HM projections for the choice of energy pathway, HM emissions projections are made for both energy pathways (Table 19). Since the CP_CLE scenario includes possibly expected climate change abatement, the change in emissions following the BL or CP scenario also provides an indication of the potential benefit of climate measures on HM emissions.

Table 19 Projected HM emissions in the UNECE –Europe for 2010 -2015-2020 following policy scenario BL_CLE _CRHM (Table 16 or figures) and the relative change due to choice of an alternative energy pathway.

Energy pathway	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
		(tonnes/yr)								
BL[1)]	2000	555	377	2350	2846	344	4144	501	15021	19503
	2010_CLE_CRHM	449	327	2328	2642	328	3750	317	8455	18025
	2015_CLE_CRHM	444	326	2489	2698	325	3649	321	8578	18369
	2020_CLE_CRHM	438	323	2645	2772	326	3426	325	8835	19006
	Additional relative change in HM emission due to expected climate change abatement (%)									
CP[2)]	2010_CLE_CRHM	-3	-2	-1	-2	-4	-2	-2	**16**	-2
	2015_CLE_CRHM	-5	-2	-1	-3	-5	-3	-2	**15**	-2
	2020_CLE_CRHM	-3	-2	-1	-3	-7	0	-2	**15**	-3

1) BL = base Line
2) CP = Climate Policy

Table 19 indicates that the climate policies will have a small but positive effect on the emissions of HM. Indeed, no major effects were expected because climate policies mainly focus on CO_2. The majority of the effect is due to a reduced use of coal. The exception is the marked increase in Se emissions. Investigation into the cause of these increasing emissions under a climate change abatement scenario revealed that the IIASA CP_CLE scenario predicts a strong increase in the glass production compared to the BL scenario. Glass production is one of the major sources of Se emissions, hence the increase in emissions. If the change in emissions for the CP scenario are compared to the BL scenario we can conclude that the projections are not very sensitive to the exact definition of the energy pathway, apparently emission reduction measures and technologies are much more important. The exception is the increase in a certain source sector such as the glass production under the CP scenario.

5.3 Spatial distribution of emission data on EMEP 50 x 50 km grid cells

The Meteorological Synthesizing Centre-East (MSC-E; Moscow, Russia) of EMEP is responsible for development and operational use of numerical models of HM airborne transport (see also http://www.msceast.org/). Transport modelling of the pollutants with the MSCE-HM model (Travnikov and Ilyin, 2005) requires, amongst others, detailed knowledge of HM input to the atmosphere. To facilitate the modelling of HM distribution over Europe, the emission data and projections are spatially distributed in the form of a grid. The emission data are treated as either point sources or area sources. Emissions of HM are distributed at the level of source sector totals by substance and country. Each source sector has its own set of geographic proxy data. Proxy data include the location of large point sources, location of traffic highways, rural and urban population maps and distribution of agricultural activities. The procedure followed is described in Berdowski et al., (1997a) but the geographical proxy data have been updated to the year 2000. An example of the gridded emissions for cadmium is presented in Figure 3. Selected total gridded emissions for all HM are presented in Annex 5.

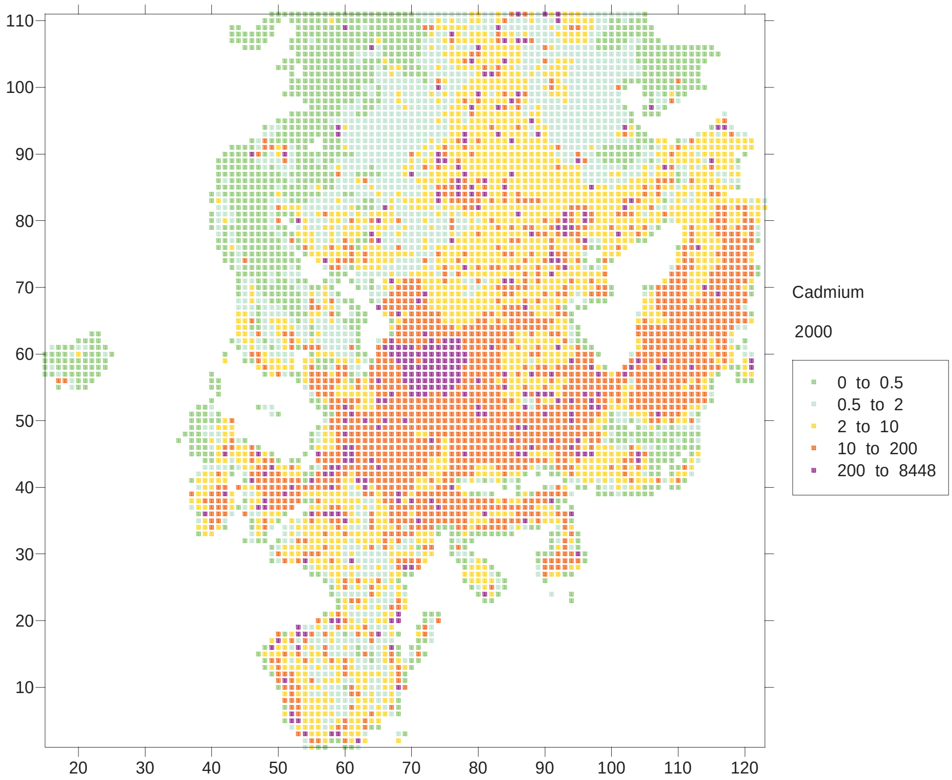


Figure 3 Distribution of the emissions of cadmium over the 50 x 50 km² EMEP grid for UNECE-Europe in 2000 (kg/grid cell).

5.4 Quantification of emission reduction due to autonomous measures and full implementation of the HM Protocol

The results from Table 17 and Table 18 have been used to quantify the relative change in HM emission for the projection years following the two policy scenarios defined in section 3.3 (Table 20).

Table 20 Relative change in projected HM emissions for UNECE-Europe compared to year 2000 emissions for two scenarios.

UNECE-Europe emission Scenario	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
					%				
2010_CLE + CRHM[1)]	-19	-13	-1	-7	-5	-10	-44	-37	-8
2015_CLE + CRHM	-20	-14	**6**	-5	-5	-12	-43	-36	-6
2020_CLE + CRHM	-21	-14	**13**	-3	-5	-17	-41	-35	-3
2010_CLE + FIHM[2)]	-40	-40	-62	-29	-7	-26	-56	-43	-33
2015_CLE + FIHM	-41	-41	-62	-27	-8	-30	-55	-42	-32
2020_CLE + FIHM	-43	-43	-62	-25	-8	-37	-54	-41	-29

1) Assuming current legislation, autonomous measures and current ratification status of the HM Protocol

2) Assuming current legislation, autonomous measures and Full Implementation of the HM Protocol by all UNECE countries

The projection of HM emissions assuming current legislation, autonomous measures and current ratification status of the HM Protocol indicates that all emissions will decline in 2010, 2015 and 2020 except for Cr. The increase in Cr emissions is due to a projected activity increase for Nickel production in countries that currently have not ratified the HM Protocol. Upon assumption that all countries ratify (and comply) with the HM Protocol the projected emissions of all HM decline sharply except for Hg. The limited change in Hg emissions is due to the fact that most measures implemented under HM Protocol or other directives are based on limit values for dust emissions. Since Hg is mostly emitted in the gaseous form and not as particulate, the emission reduction for Hg is much smaller than for other HM. However, the reduction in Hg emissions due to autonomous measures is possibly underestimated. For example, the impact of the phase out of Hg-containing products may not be fully accounted for. In the present study, Hg emissions from waste incineration are in line with the emission limit values set in the EU waste directive and/or HM Protocol. However, due to the phasing out of Hg-containing products, the Hg content of municipal waste will decrease and it is conceivable that the actual emissions may be below the limit value as laid out in the HM Protocol or EC Waste directive. Research is necessary to derive and / or check the Hg emissions from waste incineration upon increasingly banning Hg in products. This may significantly improve the accuracy of the Hg emission estimates but is outside the scope of the current study.

To further investigate the additional reduction in HM emissions due to autonomous measures and/or full implementation of the HM Protocol in 2010, 2015 and 2020 compared to the year 2000 countries have been aggregated in three country groups according to the foreseen reduction measures and policies that apply for each country (Table 21).

Table 21 Country groups, number of countries in group and country group code as used for source sector analysis in the present study.

Description	Nr. Of countries[1)]	GroupCode
All countries that have ratified the HM Protocol	20	HM Protocol
All countries not ratified HM Protocol but EU25 or/and ratified 2eS Prot	10	EU25 a/o 2nd S Protocol
No HM Protocol ratification, no 2nd S protocol ratification and not a member of EU-25	14	Other

1) See Annex 2.

The result of distributing the emissions over the country groups defined in Table 21 is presented in Table 22. The relevance of this exercise is not to discuss the absolute emission level of a country group because the number of citizens covered, prime economic activities etc. are different between the three groups. The importance lies in the changes over time following the projection years and the policy scenarios. From the relative share of source sectors for Cd, Hg and Pb over various years and two policy scenarios (Figure 4, Figure 5 and Figure 6, respectively) and Table 22, the following conclusions can be derived;

- The countries that have currently ratified the HM Protocol show a marked decrease in HM emission going from 2000 to 2010. After 2010 little additional reduction occurs independent of the policy scenario.
- For Cd, Hg and Pb, the relative source sector contributions do not dramatically change over the period 2000-2020 with the exceptions of changing shares of Cd from residential combustion (+) and Public heat and power (-) (country group “Other”, Figure 4), Hg from Public heat and power (+) and waste (-) (country group “HM Protocol ratified”, Figure 5) and Pb from Industry (+) and Road transport (-) (country groups “HM Protocol ratified and Other”, Figure 6).
- The countries that have presently not ratified the HM Protocol but are part of the EU-25 and/or signed the 2nd S protocol also show a major reduction going from 2000 to 2010. This is because we assume that all EU-25 countries will comply with the EU directives in 2010. The change going from complying with the EU directives and/or 2nd S protocol to ratifying and complying with the HM Protocol (scenario BL_CLE_FIHM, Table 22) is limited and only visible for Cr and Ni.
- The countries that have not ratified the HM Protocol, are not a member of the EU-25 and have not ratified the 2nd S protocol show a truly different pattern. Here the emission increases going from 2000 to 2010, 2015 and 2020 for the

BL_CLE_CRHM scenario. However, when these countries would comply with the HM Protocol (BL_CLE_FIHM scenario) major (~ 50%) emission reductions are achieved with the exception of Hg for the same reasons as discussed earlier; Hg is mostly emitted in the gaseous phase.

Table 22 HM emission by country group in 2000, projected HM emissions for 2010, 2015 and 2020 following policy scenario BL_CLE_CRHM and projected HM emissions following policy scenario BL_CLE_FIHM.

Country group[1)]	**year**	**scenario**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
							tonnes/yr				
HM_Protocol ratified	2000		113	85	463	735	109	985	2240	109	5669
HM_Protocol ratified	2010		81	59	299	739	85	720	1372	69	5103
HM_Protocol ratified	2015		78	58	296	754	83	641	1389	68	5301
HM_Protocol ratified	2020		81	58	298	778	88	604	1457	70	5701
HM_Protocol ratified	2010	BL_CLE_FIHM	81	59	299	739	85	720	1372	69	5103
HM_Protocol ratified	2015	BL_CLE_FIHM	78	58	296	754	83	641	1389	68	5301
HM_Protocol ratified	2020	BL_CLE_FIHM	81	58	298	778	88	604	1457	70	5701
EU25 a/o 2nd S protocol	2000		212	96	326	733	85	1068	3183	257	5305
EU25 a/o 2nd S protocol	2010		108	59	195	402	73	681	2579	100	3242
EU25 a/o 2nd S protocol	2015		100	55	192	386	71	622	2525	104	3183
EU25 a/o 2nd S protocol	2020		88	47	177	373	67	411	2531	106	3198
EU25 a/o 2nd S protocol	2010	BL_CLE_FIHM	108	59	151	402	73	659	2579	100	3240
EU25 a/o 2nd S protocol	2015	BL_CLE_FIHM	100	55	145	385	71	598	2525	104	3182
EU25 a/o 2nd S protocol	2020	BL_CLE_FIHM	88	47	128	373	67	387	2531	106	3197
Other[2)]	2000		230	196	1560	1377	150	2091	9597	135	8529
Other[2)]	2010		260	208	1833	1501	170	2349	4504	148	9679
Other[2)]	2015		265	214	2001	1559	171	2386	4663	149	9885
Other[2)]	2020		269	218	2169	1621	172	2411	4847	149	10107
Other[2)]	2010	BL_CLE_FIHM	143	107	434	891	160	1684	2616	116	4629
Other[2)]	2015	BL_CLE_FIHM	146	110	454	931	161	1663	2774	118	4736
Other[2)]	2020	BL_CLE_FIHM	149	112	474	975	162	1631	2958	118	4868
Total UNECE	2000		555	377	2350	2846	344	4144	15021	501	19503
Total UNECE	2010		449	327	2328	2642	328	3750	8455	317	18025
Total UNECE	2015		444	326	2489	2698	325	3649	8578	321	18369
Total UNECE	2020		438	323	2645	2772	326	3426	8835	325	19006
Total UNECE	2010	BL_CLE_FIHM	332	226	884	2033	318	3063	6566	285	12973
Total UNECE	2015	BL_CLE_FIHM	325	222	894	2070	315	2903	6689	290	13218
Total UNECE	2020	BL_CLE_FIHM	318	217	900	2126	316	2622	6946	294	13766

1) See Annex 2.

2) No HM Protocol ratification and/or no 2nd S protocol ratification and/or no EU-25 member state

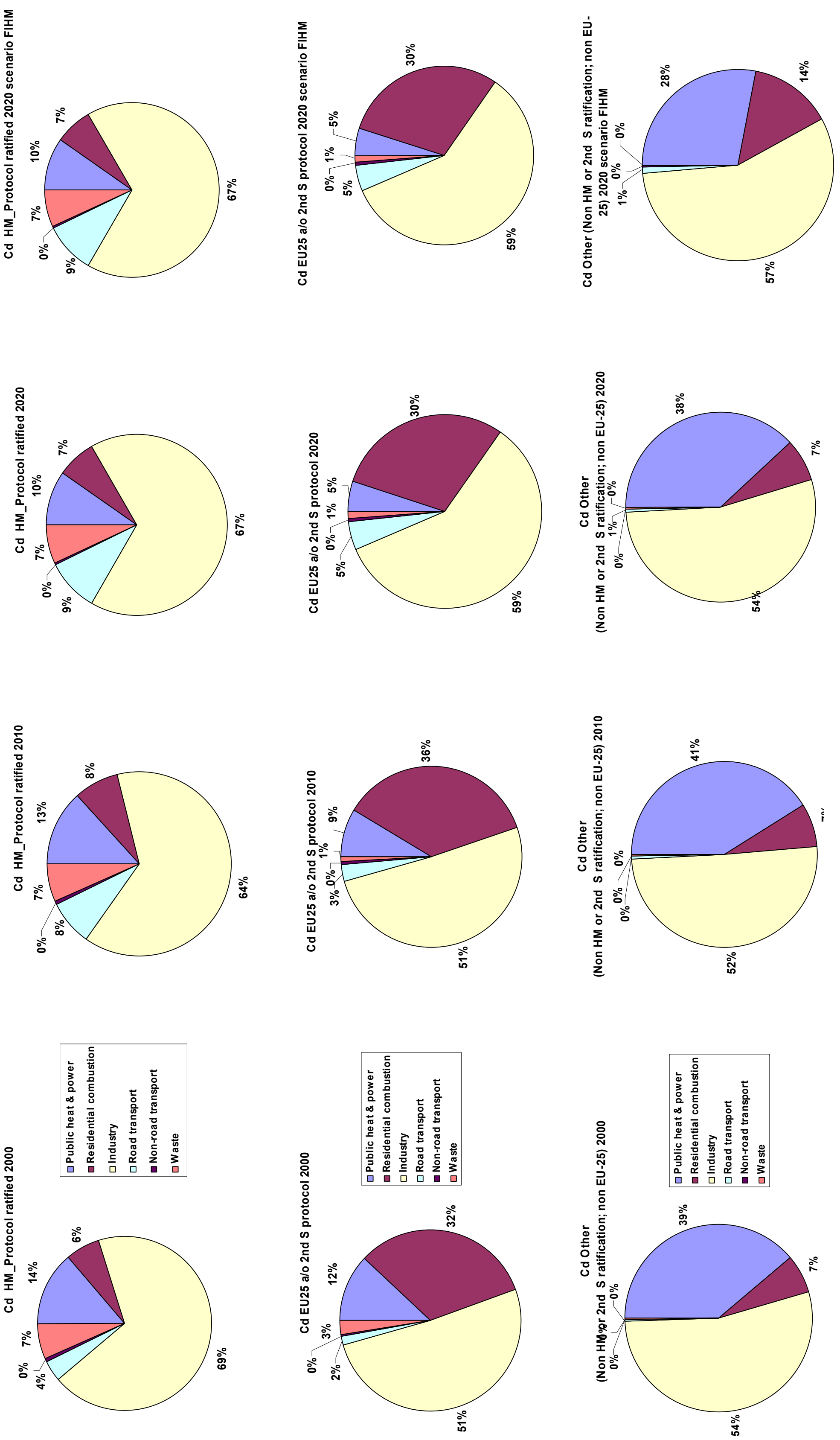


Figure 4 *Relative source sector contributions to Cadmium emissions for three different country groups in 2000, 2010, 2020 with current ratification and autonomous measures and 2020 assuming Full Implementation of the HM Protocol in the UNECE.*

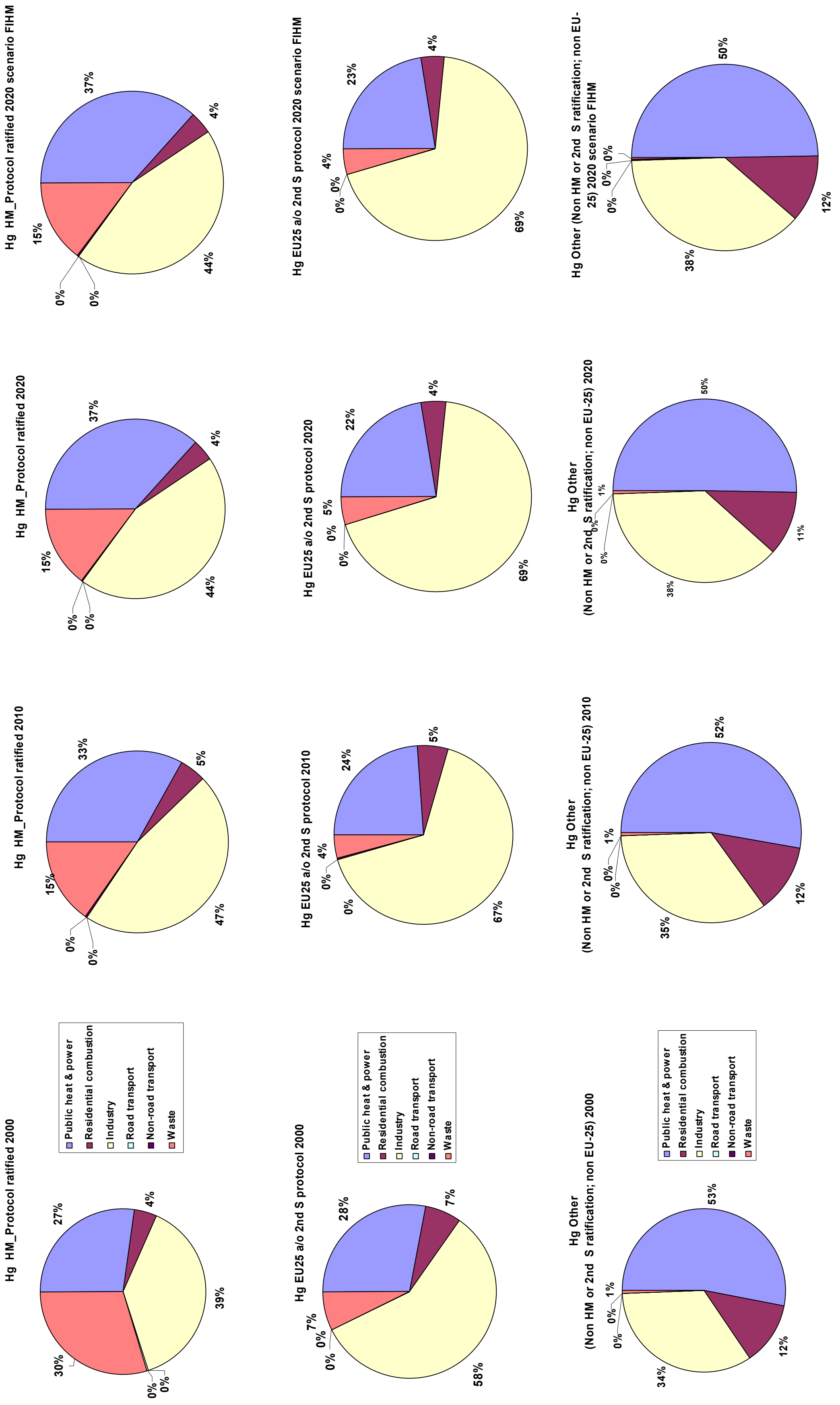


Figure 5 *Relative source sector contributions to Mercury emissions for three different country groups in 2000, 2010, 2020 with current ratification and autonomous measures and 2020 assuming Full Implementation of the HM Protocol in the UNECE.*

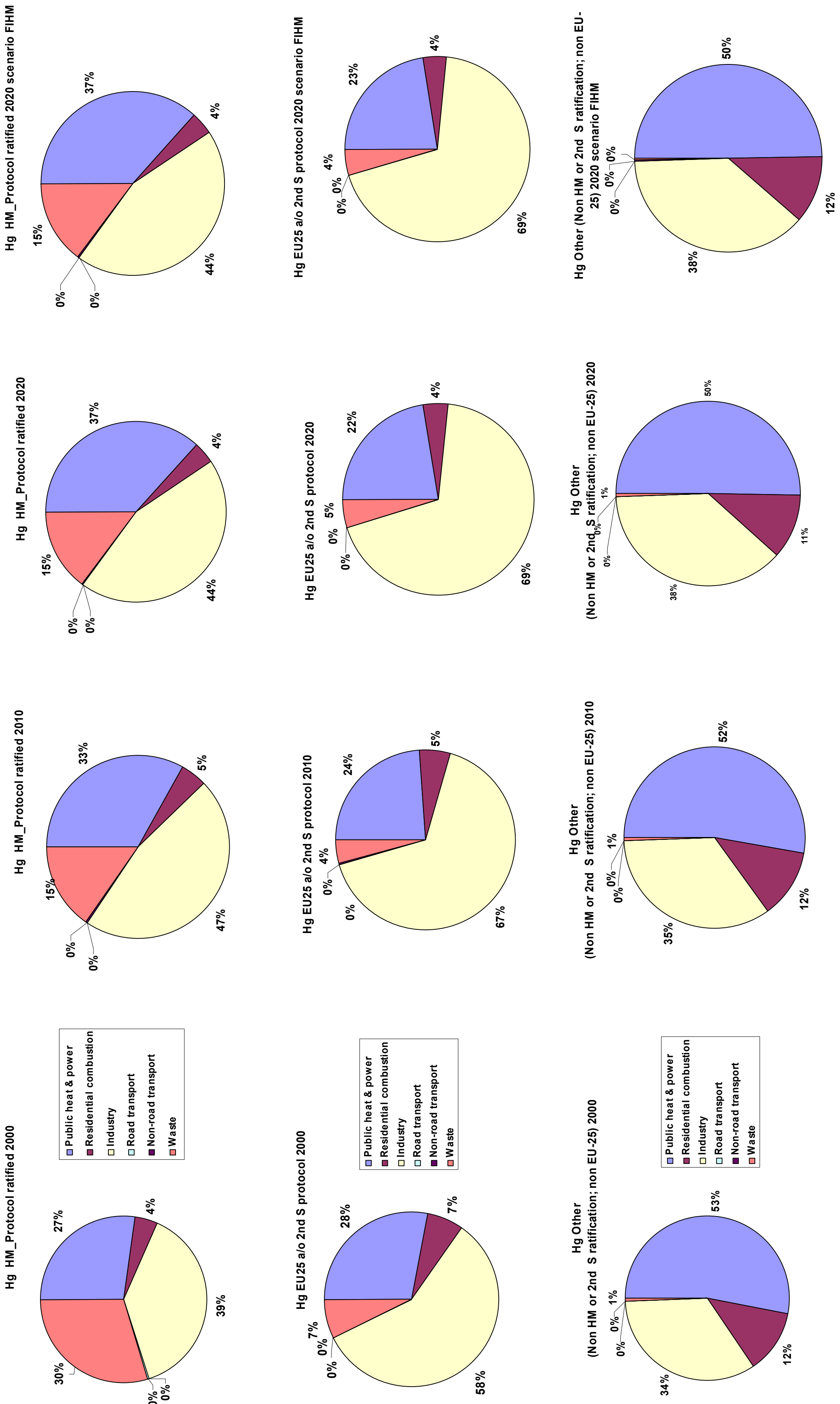


Figure 6 *Relative source sector contributions to lead emissions for three different country groups in 2000, 2010, 2020 with current ratification and autonomous measures and 2020 assuming Full Implementation of the HM Protocol in the UNECE.*

The EC is a party to the CLRTAP and the UNECE protocols and thereby bound to integrate the obligations of these protocols in EC legislation. It is therefore not surprising that many of the foreseen emission reductions that can be achieved through the HM Protocol are also achieved through e.g. implementation of the IPPC directive. Since we chose to first achieve reductions through "autonomous" measures and than quantify the additional reduction from implementation of the HM Protocol the conclusion is that for countries that have to comply with the EC directives and or 2nd S protocol, ratifying and complying with the HM Protocol will result in little additional costs and effort as the majority of the reductions and obligations are also covered by the EC directives. This is further confirmed and visualized in two "subtraction maps". First, the change in Cd emission as projected for the year 2010 assuming current legislation, autonomous measures and current ratification of the HM Protocol compared to the year 2000 inventory ().

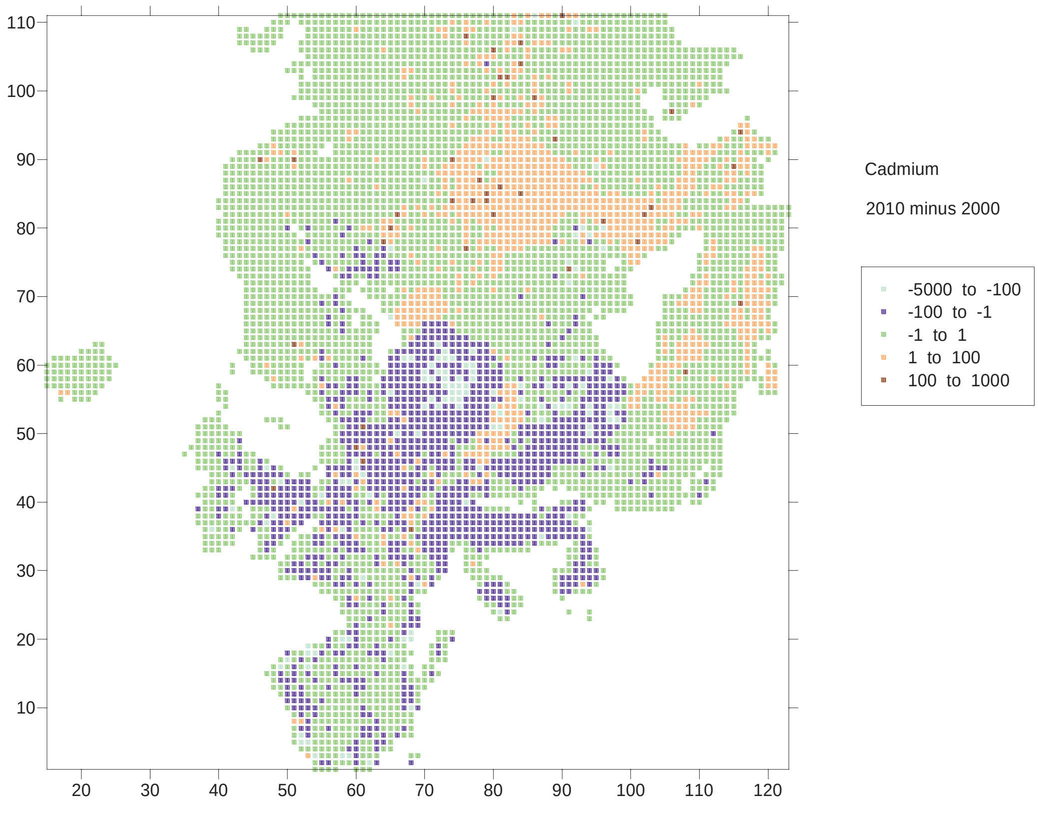


Figure 7 *The difference between projected cadmium emissions from UNECE-Europe in the year 2010 and the emission inventory for the year 2000 (negative values indicate an emission reduction) (kg/grid cell).*

It can be seen that emission reductions (negative values; blue and green cells) are almost exclusively limited to the EU-25 but within this group no pattern is visible that distinguishes the countries that have ratified the HM Protocol. This does not imply that the HM Protocol is of little value for EC countries as the question which directive or protocol will be implemented first is a chicken and the egg question. The conclusion is that for countries that comply with the EC directives, compliance with the HM Protocol is relatively easily achieved. Vice versa, countries that comply with the HM Protocol can relatively easily comply with the relevant parts of the EC directives (see section 3.4. Description of implemented autonomous measures). Figure 8 shows the emission according to the 2020 projection for current legislation and ratification minus the emission in 2020 assuming Full Implementation of the HM Protocol for all UNECE-Europe countries. The result is practically no change for the country groups HM_protocol ratified and EU25 a/o 2^{nd} S protocol (Table 21) but important emission reductions for the other countries.

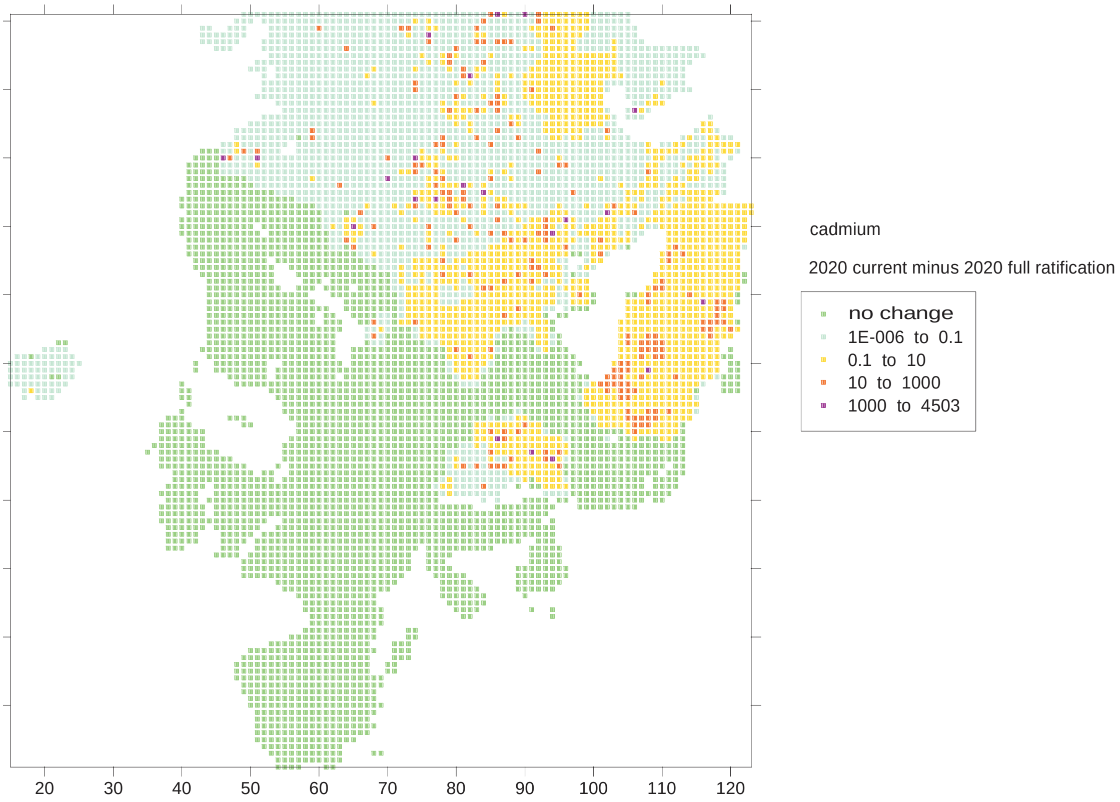


Figure 8 The change in cadmium emissions going from 2020 with current legislation, current ratification of the HM Protocol and autonomous measures to 2020 assuming full implementation of the HM Protocol for the entire UNECE-Europe domain (kg/grid cell).

5.5 Quantification of side effects for particulate matter (PM_{10} $PM_{2.5}$)

There is a strong link between particulate matter (PM) and heavy metal emissions. Many HM are particle-bound (see section 3.5). Therefore measures aimed at emission reduction of these substances will also result in a reduction of PM. In fact, most emission limit values in the HM Protocol are expressed as maximum allowable concentrations of PM. A semi-quantitative assessment of the expected PM emission reduction as a result of the Protocols is made.

The results of the CEPMEIP Coordinated European Particulate Matter Emission Inventory Program (Visschedijk et al, 2004) are used as a starting point and base inventory. CEPMEIP comprises a Pan European emission inventory of TSP, PM10 and PM2.5 for 1995 and covers all countries included in the present study. However, there are no suitable PM emission projections for 2010, 2015 or 2020 available. The assessment of the side effects for PM will therefore be based on 1995 data, this can only be regarded as a rough approximation of the actual effects in 2010, 2015 and 2020.

The principal question in the PM side effect assessment is: What is the incremental effect of full implementation of the HM Protocol on PM emission, assuming all foreseen autonomous emission policies to have entered into force according to schedule. This means that all EU Directives (including the IPPC) have been fully implemented in all of the EU(25). So, an assessment has been made of the effect of the HM Protocol on PM, based on the situation in the late 1990ties, for all non-EU(25) countries in UNECE Europe (thus assuming no additional effect of the Protocol over the IPPC Directive).

Our estimate shows that an emission reduction of about 3.7 Mt TSP, 1.2 Mt PM10 and 0.28 Mt PM2.5 will be the result of full implementation of the HM Protocol. Compared to the total European PM emissions in 1995, this comes down to 25% of total TSP, 16% of total PM10 and 6% of total PM2.5. The largest reduction would be achieved in the power generation sector, 3.15 of the total 4.03 Mt for TSP, 0.98 of 1.54 Mt for PM10 and 0.19 of 0.48 Mt for PM2.5. Reductions for the sector Industrial Combustion range from 0.46 of 1.35 Mt for TSP to 0.09 of 0.79 Mt for PM2.5. Smaller reductions are furthermore achieved in Industrial Processes and Waste Incineration. Again, as is also discussed at the end of section 5.4, it is important to realize that as the EC is a party to the CLRTAP and the UNECE protocols obligations of these protocols are integrated in and/or in line with EC legislation. Hence the choice to first implement the IPPC directive for the EC25 and than quantify the additional PM reduction due to implementation of the HM Protocol greatly influences the additional PM reduction attributed to the HM Protocol. If the procedure would be followed differently (first HM Protocol, than other autonomous measures) the side effect of the HM Protocol on PM reduction is much larger.

5.6 Indicative trend of HM emissions from 1990 to 2000

In 1997 a rather similar study was published by Berdowski et al. (1997a) “The European Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990”. All Parties to OSPARCOM, Helcom and the Convention on LRTAP have been asked to cooperate with the inventory and to submit official emission data. The results of Berdowski et al. (1997a) are, amongst others, a European emission inventory for heavy metals and persistent organics for the year 1990 partly based on country submissions of emission data and for the lacking countries, sources or compounds, TNO default emission estimates were used to complete the inventory. The results of the Berdowski et al. inventory for the year 1990 can be compared to our year 2000 inventory for an indicative trend analysis except for Se as Berdowski et al. (1997a) did not estimate 1990 Se emissions. The country emissions in 1990 and 2000 for the priority HM (Cd, Hg and Pb) are summarized in

Table 23 and other HM in *Table 24* (As, Cr, Cu, Ni and Zn). The comparison can only be indicative because both the 1990 and 2000 inventory are a mix of official data and expert estimates. This implies that an estimate for a particular country in 1990 may, for example, be based on expert judgment whereas the year 2000 may be an official country estimate. The difference between the 1990 and 2000 estimates may be due to “real” changes in activities or emissions but may also be (partly) caused by different emission estimation methodologies, slight differences in sector coverage and/or retrospective adjustments of official country emission data. Furthermore, the 1990 inventory covers fewer countries than the present study because since the Berdowski et al. (1997a) study, countries have joined the UNECE CLRTAP. Therefore, the 1990-2000 comparison cannot be made for the entire domain but only for the majority of the countries, as listed in Table 23 and *Table 24*. Overall the emission of Cd, Hg and Pb decreased with 45%, 34% and 66%, respectively. These are substantial reductions. The emission reduction for Hg lags behind because much of the Hg emissions are in the gaseous phase and are less susceptible to general emission reduction strategies that often focus on dust removal. The reduction in lead emissions is rather pronounced due to the phase out of leaded petrol, one of the major sources of lead emissions. From 1990-2000 the overall emission of As, Cu, N and Zn decreased with 60, 56, 68 and 31%, respectively, whereas Cr emissions remained stable (*Table 24*).At the individual country level Cr emissions are far from stable. As can be seen from *Table 24*, the considerable reductions of Cr emissions in most countries are counterbalanced by increasing emissions in several other countries. However, the most important reason why overall no emission reduction for Cr is observed is because Berdowski et al. (1997a) did not include Ni production as a major source of Cr. Hence the 1990 Cr emissions are probably underestimated and it is expected that in reality Cr emissions did also decrease from 1990-2000.

Small differences between the overall changes as shown in Table 23 and *Table 24* compared to the earlier presented summarized 1990 emissions in Table 16 are due to representation of countries not covered by Berdowski et al. (1997a) by their year 2000 emissions in Table 16.

Table 23 Emissions of cadmium, mercury and lead for 1990 (Berdowski et al., 1997a) and the year 2000 (this study) and the relative change over the decade 1990-2000.

ISO3	Cd			Hg			Pb		
	1990 Tonnes/yr	2000	Change (%)	1990 Tonnes/yr	2000	Change (%)	1990	2000	Change (%)
ALB	0.6	0.2	-69	0.5	0.2	-60	33.4	43.2	*29*
AUT	5.1	1.4	-72	4.3	1.2	-73	215.0	13.9	-94
BEL	9.9	2.7	-72	8.9	2.3	-74	716.0	133.8	-81
BGR	8.4	11.0	*31*	6.9	4.2	-39	317.0	214.1	-32
BIH	0.4	1.7	*315*	0.2	2.0	*853*	8.6	96.9	*1023*
BLR	6.6	1.4	-79	0.1	0.4	*299*	736.0	51.0	-93
CHE	4.2	2.2	-49	6.8	2.6	-61	520.0	113.6	-78
CYP	0.2	0.6	*190*	0.3	0.6	*94*	0.9	74.0	*8065*
CZE	12.0	2.8	-76	9.3	3.8	-59	337.0	107.7	-68
DEU	31.5	21.1	-33	113.0	56.0	-50	2347.0	587.6	-75
DNK	2.1	1.0	-53	6.9	4.9	-29	179.0	9.6	-95
ESP	36.7	15.5	-58	20.2	21.8	*8*	4674.0	932.1	-80
EST	3.9	0.7	-82	2.0	0.6	-73	171.0	40.7	-76
FIN	3.7	1.4	-62	3.0	0.5	-84	215.0	37.5	-83
FRA	14.8	10.5	-29	32.5	13.4	-59	4414.0	234.1	-95
GBR	24.9	7.2	-71	25.6	8.8	-66	2703.0	192.8	-93
GRC	4.5	2.8	-36	7.1	6.7	-7	505.0	132.4	-74
HRV	3.2	1.0	-69	1.1	0.4	-62	466.0	146.9	-68
HUN	4.6	2.7	-40	4.2	4.2	0	639.0	38.7	-94
IRL	1.6	1.3	-16	1.6	1.8	*9*	134.0	8.8	-93
ISL	0.2	0.1	-51	0.0	0.1	*127*	6.4	0.2	-97
ITA	59.8	11.1	-82	11.8	10.2	-14	1642.0	908.9	-45
LTU	2.8	1.4	-52	0.0	0.6	*NA*[a]	246.0	16.1	-93
LUX	1.1	0.1	-96	0.8	0.3	-64	73.5	3.4	-95
LVA	3.2	0.6	-82	0.3	0.1	-56	218.0	8.2	-96
MDA	1.8	0.4	-79	1.5	0.1	-90	168.0	3.2	-98
MKD	9.1	9.8	*7*	1.5	1.8	*24*	210.0	87.0	-59
NLD	2.2	1.2	-47	2.6	0.6	-78	266.0	44.1	-83
NOR	2.4	0.7	-70	2.3	1.0	-57	226.0	6.0	-97
POL	91.6	50.4	-45	33.3	25.6	-23	1372.0	647.5	-53
PRT	3.0	3.2	*9*	5.5	6.8	*24*	631.0	39.5	-94
ROM	21.6	17.4	-20	7.5	9.2	*22*	585.0	604.4	*3*
RUS	159.0	111.5	-30	86.2	80.1	-7	10148.0	5861.8	-42
SVK	9.7	7.2	-25	12.4	4.4	-65	166.0	74.3	-55
SVN	1.0	1.5	*50*	0.9	0.6	-26	123.0	37.5	-70
SWE	2.0	0.4	-79	1.5	0.7	-49	537.0	11.8	-98
UKR	54.2	23.7	-56	36.0	22.3	-38	3878.0	1703.2	-56
YUG	8.3	8.7	*4*	3.9	5.5	*42*	597.0	299.8	-50
Total	***612***	***339***	***-45%***	***463***	***306***	***-34%***	***40424***	***13566***	***-66%***

[a] NA = Not Available (division by zero)

Table 24 Emissions of As, Cr, Cu, Ni, and Zn for 1990 (Berdowski et al., 1997a) and the year 2000 (this study) and the relative change over the decade 1990-2000.

ISO3	As			Cr			Cu			Ni			Zn		
	1990	2000	change	1990	2000	change	1990	2000	change	1990	2000	change	1990	2000	change
	Tonnes/yr		%	Tonnes/yr		%	Tonnes/yr		%	Tonnes/yr		%	Tonnes/yr		%
ALB	1.2	0.2	-86	1.6	0.6	-66	6.1	1.2	-81	16.5	5.8	-65	17.0	4.1	-76
AUT	4.5	2.8	-38	5.5	11.3	*105*	21.7	32.6	*50*	30.4	43.1	*42*	97.4	187.7	*93*
BEL	11.4	3.8	-66	58.2	24.9	-57	54.8	26.8	-51	94.0	52.7	-44	514.0	166.3	-68
BGR	10.2	3.5	-66	20.8	7.0	-66	41.4	18.7	-55	177.0	26.4	-85	219.0	130.2	-41
BIH	0.1	2.2	-	0.6	1.7	*193*	1.5	9.2	*524*	0.2	7.1	*2883*	7.3	69.0	*842*
BLR	12.3	3.4	-73	27.0	6.3	-77	26.5	14.5	-45	601.0	94.4	-84	69.9	196.8	*181*
CHE	1.3	0.8	-36	6.7	3.5	-48	17.8	21.6	*22*	27.5	7.4	-73	861.0	558.3	-35
CYP	0.6	0.6	0	1.6	1.6	0	0.8	1.6	*109*	20.4	25.2	*23*	1.5	2.5	*61*
CZE	10.2	11.6	*14*	25.0	16.6	-33	53.9	43.7	-19	99.2	47.2	-52	423.0	319.5	-24
DEU	122.0	34.5	-72	254.0	73.6	-71	468.0	273.3	-42	288.0	247.5	-14	1600.0	1657.9	*4*
DNK	3.8	1.0	-74	5.7	4.3	-24	23.4	11.6	-50	43.9	14.2	-68	66.0	65.9	0
ESP	22.2	56.1	*153*	83.9	35.9	-57	1860.0	149.5	-92	1771.0	256.5	-86	3419.0	789.6	-77
EST	9.7	9.7	0	14.2	9.7	-32	25.5	3.5	-86	25.3	7.9	-69	89.7	53.0	-41
FIN	4.6	4.5	-2	10.4	28.0	*169*	36.7	18.7	-49	71.3	33.2	-53	143.0	70.6	-51
FRA	17.9	25.3	*41*	375.0	259.4	-31	108.0	177.2	*64*	321.0	221.7	-31	1806.0	1441.4	-20
GBR	166.0	38.0	-77	80.7	69.4	-14	99.9	48.2	-52	635.0	125.3	-80	1388.0	413.2	-70
GRC	5.6	4.0	-29	12.1	35.0	*189*	31.7	18.2	-43	110.0	99.6	-9	134.0	76.0	-43
HRV	2.6	1.1	-59	13.3	4.3	-68	17.3	9.8	-43	77.2	26.5	-66	91.9	61.1	-34
HUN	13.9	5.7	-59	12.4	6.7	-46	39.2	18.7	-52	35.8	37.2	*4*	59.0	40.2	-32
IRL	2.3	1.8	-24	5.2	3.9	-25	10.2	8.8	-14	37.0	46.2	*25*	35.8	20.5	-43
ISL	0.1	0.1	-30	0.4	0.2	-30	2.1	0.4	-80	4.7	3.5	-26	4.1	2.4	-41
ITA	202.0	42.6	-79	235.0	46.2	-80	205.0	72.4	-65	1181.0	107.9	-91	1143.0	1430.9	*25*
LTU	7.4	0.8	-89	5.1	2.4	-52	9.0	6.7	-25	65.4	26.6	-59	11.6	63.9	*451*
LUX	0.9	0.1	-92	3.3	0.3	-90	12.2	1.3	-90	14.7	0.7	-95	67.4	36.7	-46
LVA	19.4	0.6	-97	12.9	5.7	-56	16.1	4.1	-75	82.1	11.0	-87	25.9	56.5	*118*
MDA	3.8	0.5	-87	8.8	0.6	-93	9.4	1.6	-83	48.4	5.9	-88	53.6	16.5	-69
MKD	0.7	0.8	*6*	1.4	1.3	-9	4.0	3.4	-14	14.0	9.5	-32	412.0	439.6	*7*
NLD	1.5	1.3	-16	10.3	5.6	-46	59.9	15.5	-74	101.0	53.2	-47	383.0	103.4	-73
NOR	1.0	2.5	*151*	3.6	8.8	*142*	46.4	19.3	-58	37.0	56.7	*53*	78.0	61.8	-21
POL	82.1	50.4	-39	155.0	84.3	-46	599.0	374.5	-37	370.0	251.6	-32	3092.0	2173.0	-30
PRT	4.9	4.5	-8	11.9	12.4	*4*	22.7	21.2	-6	139.0	93.7	-33	90.6	121.1	*34*
ROM	47.2	4.6	-90	53.2	11.8	-78	112.0	25.8	-77	126.0	82.1	-35	605.0	679.5	*12*
RUS	201.0	125.5	-38	417.0	1400.6	*236*	1161.0	800.3	-31	3817.0	1368.4	-64	6343.0	4832.0	-24
SVK	150.0	11.2	-93	78.8	8.1	-90	103.0	23.7	-77	78.5	23.6	-70	111.0	59.2	-47
SVN	0.6	0.8	*31*	1.3	1.4	*10*	3.8	4.5	*17*	11.3	4.4	-61	28.3	25.2	-11
SWE	5.5	0.6	-89	23.0	6.5	-72	26.5	15.1	-43	26.0	17.7	-32	228.0	92.3	-60
UKR	62.3	30.3	-51	164.0	64.5	-61	366.0	198.4	-46	847.0	147.6	-83	2171.0	1298.4	-40
YUG	9.1	5.2	-43	8.7	4.8	-44	57.0	31.2	-45	50.0	19.8	-60	202.0	119.4	-41
Total	1222	493	-60%	2208	2269	3%	5759	2527	-56%	11495	3709	-68%	26092	17936	-31%

6. Further reduction of HM emissions

Even upon full implementation of the HM Protocol in all UNECE countries, HM emissions will continue. In this chapter a preliminary analysis is made of the potential to further reduce HM emissions. The starting point is the assumption that all UNECE countries implement the current HM Protocol. Therefore, the emission projections under full implementation of the HM Protocol (Table 18) can be used as an approximation of the remaining HM emissions in the future. A key source analysis of these projected emissions provides insight in the remaining source strengths which subsequently can be discussed in terms of their potential for (further) reduction.

6.1 Key source analysis of remaining emissions after full implementation of the HM Protocol

The relative contribution of the source sectors to total HM emission in UNECE Europe at the level of the common format (Table 4) are presented in Table 25. The individual source sector contributions in the year 2000 and projected contributions in the year 2020 assuming full implementation of the HM Protocol are shown for Cd, Hg, Pb, in Figure 9, Figure 10 and Figure 11, respectively the other six HM are depicted in Figure 12-Figure 17. Since the sectors Solvent and Product Use and Agriculture do not contribute to the HM emission they have been removed from the table and figures. Figure 9-Figure 17 illustrate once more that industrial combustion and processes is an important source sector for all HM, even though considerable reduction has been achieved since the year 2000. The emission decrease for Hg is rather limited (Figure 10) because dust reduction measures are less effective for this element as has been discussed earlier. For cadmium the majority of the remaining emissions is attributed to industrial combustion and processes but for Hg, Public power and heat production remains important (Figure 10). For lead, road transport remains an important sector (Figure 11), despite the phase out of leaded fuel (see section 6.3 for a more detailed discussion). The level of the common format provides general insight but is not detailed enough to discuss further reduction options. A further investigation is necessary to breakdown the contributions at the level of the individual activities (CRFsubID, annex 3).

Table 25 *Relative contribution of source sectors to remaining HM emissions upon ratification (and compliance) of the HM Protocol by all UNECE countries.*

	Public power and heat	Residential combustion	Industrial combustion and processes	Road transport	Non-road transport	Waste in-cineration	Total
As	22	11	66	0	0	1	100%
Cd	18	15	60	4	0	2	100%
Cr	8	10	75	3	0	3	100%
Cu	5	9	36	31	17	2	100%
Hg	40	8	46	0	0	5	100%
Ni	40	10	45	2	2	0	100%
Pb	6	4	42	45	2	1	100%
Se	18	3	77	1	1	0	100%
Zn	10	7	65	13	0	5	100%

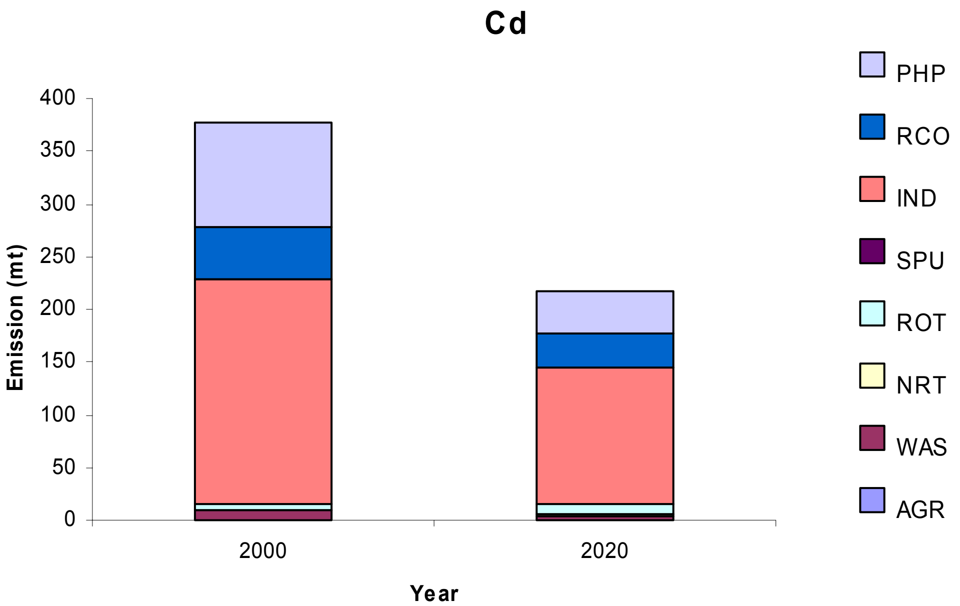


Figure 9 *Source sector contributions to cadmium emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.*

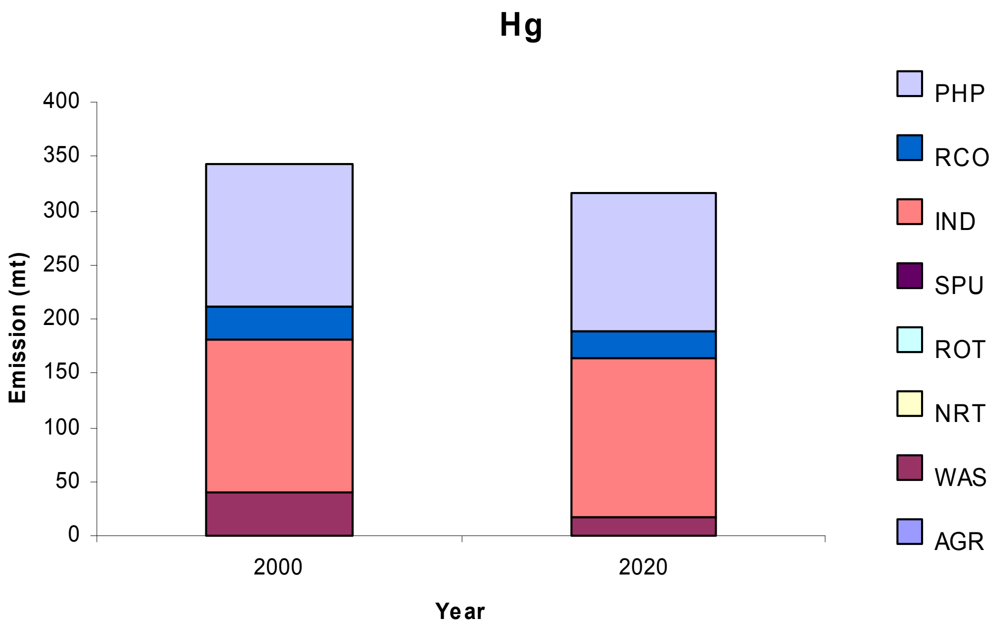


Figure 10 *Source sector contributions to mercury emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.*

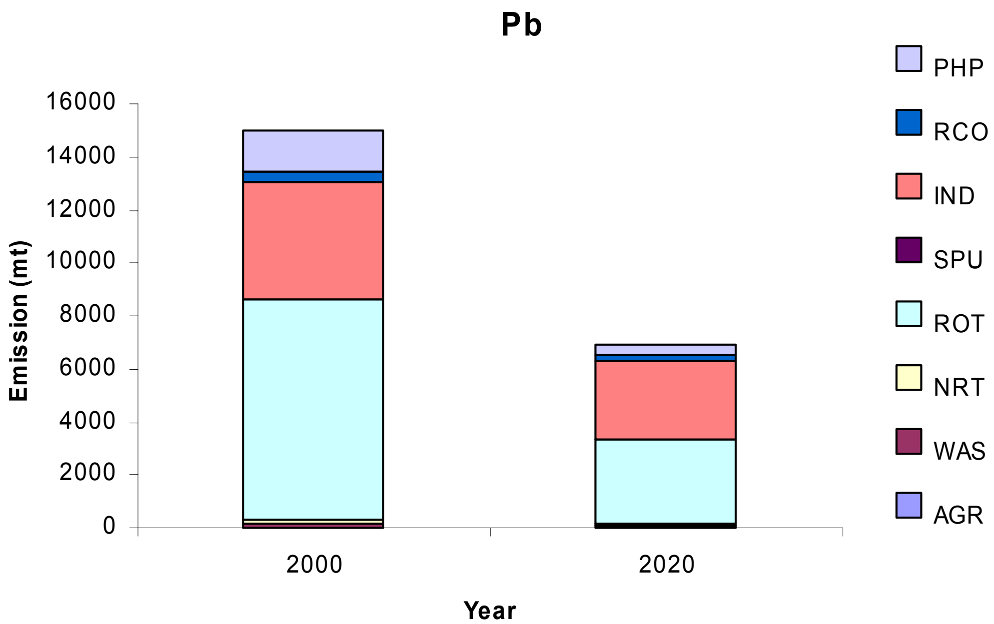


Figure 11 *Source sector contributions to lead emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.*

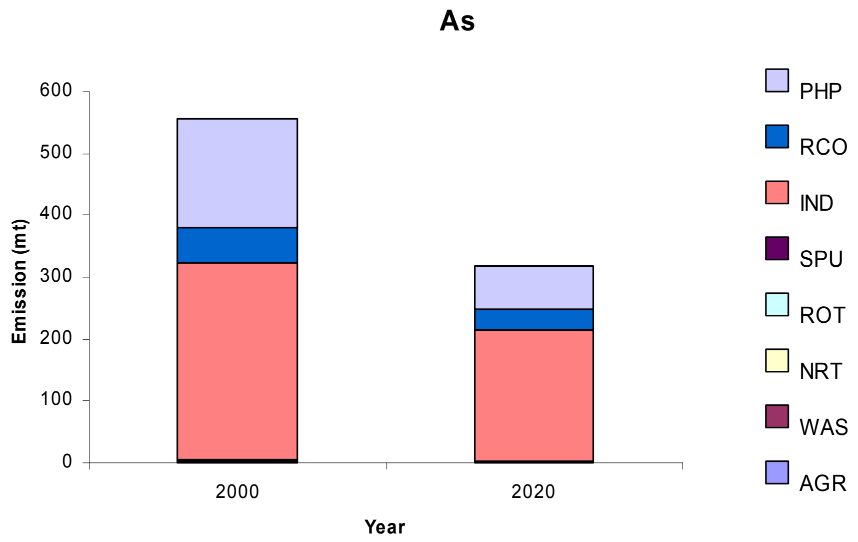


Figure 12 Source sector contributions to arsenic emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.

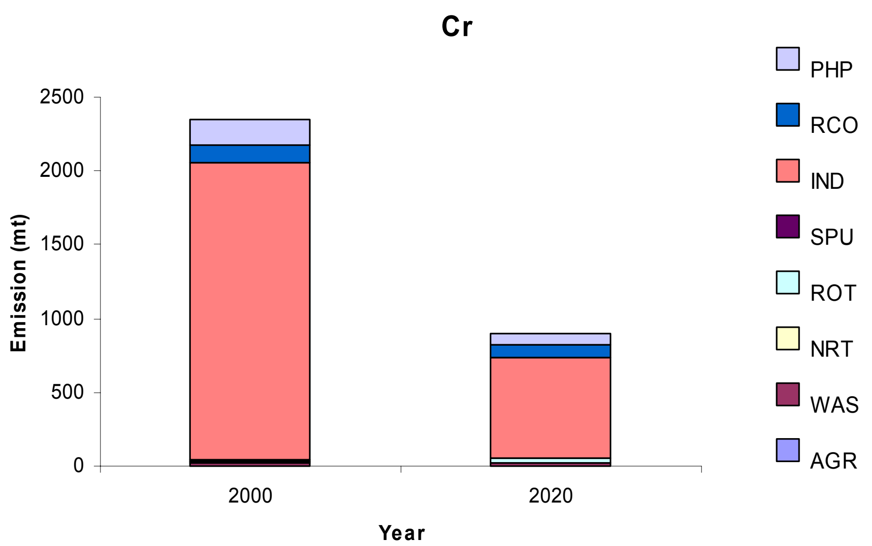


Figure 13 Source sector contributions to chromium emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.

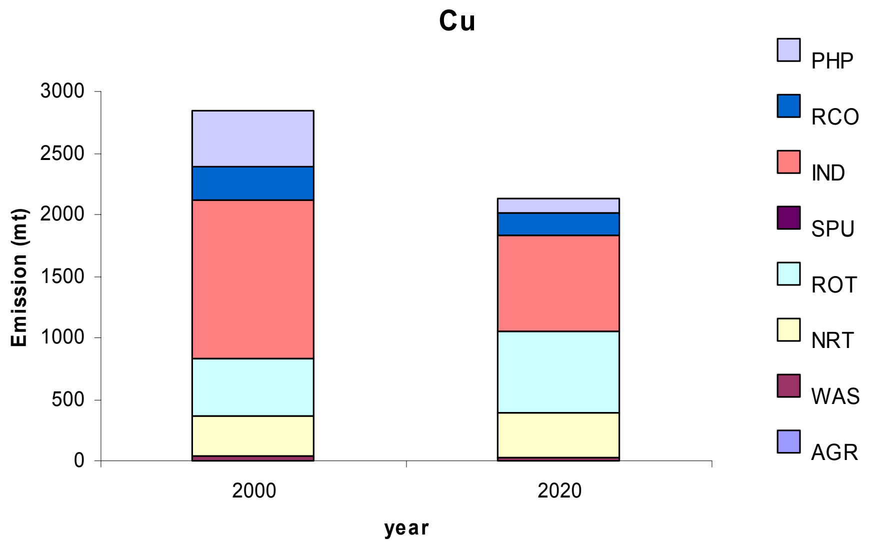


Figure 14 *Source sector contributions to copper emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.*

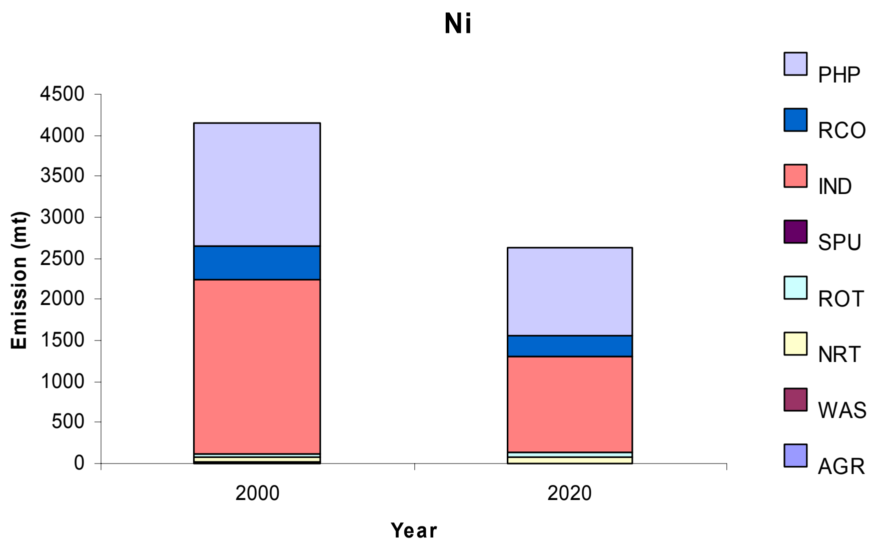


Figure 15 *Source sector contributions to nickel emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.*

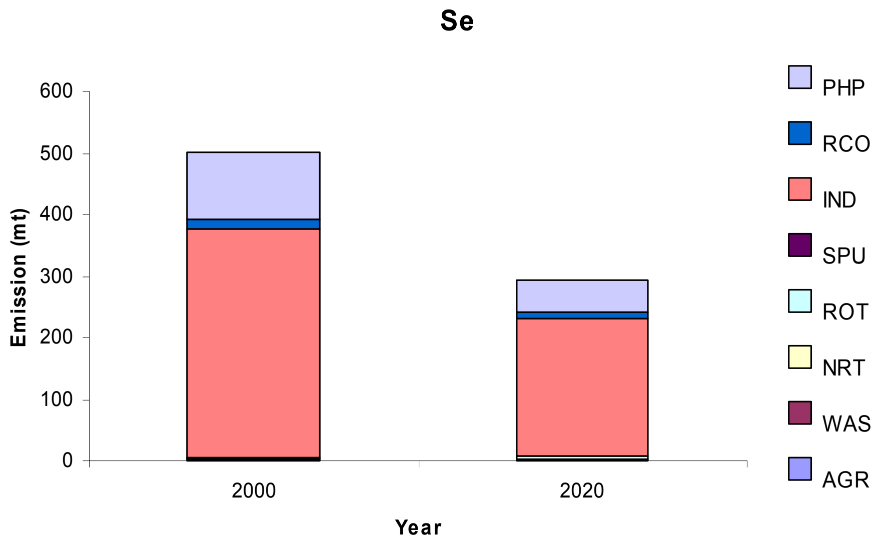


Figure 16 Source sector contributions to selenium emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.

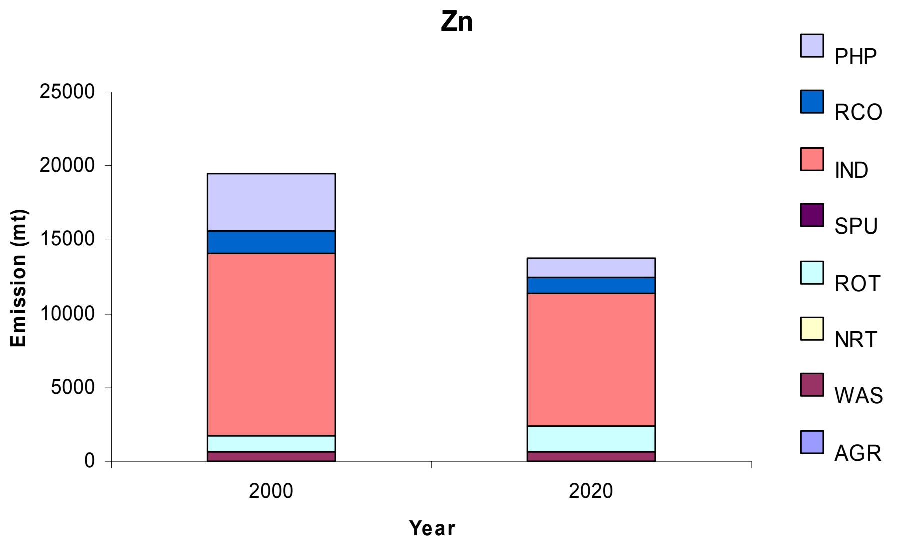


Figure 17 Source sector contributions to zinc emissions in the year 2000 and projected year 2020 contribution assuming full implementation in UNECE-Europe.

6.2 Identification of target source sectors for further emission reduction

The projected relative source contributions to the UNECE-Europe total HM emission for the year 2020, assuming all countries implemented the HM Protocol, are depicted in Figure 18, Figure 19 and Figure 20 for Cd, Hg and Pb, respectively. Compared to previously presented figures or tables (e.g. Table 25) the industry sector is split into the individual processes to produce a more detailed picture. From Figure 18, Figure 19 and Figure 20 those sectors that make a significant contribution to the emission of HM can be identified and hence these sectors could be candidates for further emission reduction measures. In this chapter we will discuss the 12 most important sectors for Cd, Hg and Pb emission. The measures to reduce three priority metals are in many cases about equally effective for the other six HM.

Before the source categories are discussed individually, some general observations can be made, based on Figure 18, Figure 19 and Figure 20. Firstly, after full implementation of the Protocol, our forecast is that there will be no remaining sources that dominate the emission of a certain substance, perhaps with the exception of road transport for Pb and public heat and power production and cement production for Hg. Secondly, among the remaining sources, there are none for which no reasonably effective emission control has been applied. The remaining sources listed in the figures are important in spite of the measures taken. Hence further emission reduction will involve replacing one control technique with another (more effective one), or adding additional technologies. The projected relative source contributions to the UNECE-Europe total As, Cr, Cu, Ni, Se and Zn emission for the year 2020, assuming all countries implemented the HM Protocol, are depicted in Figure 21-Figure 26, repectively. Activities that partly dominate emissions of a particular species are primary Ni prodcution for Cr (Figure 22); Heat /power plants and Industrial combustion for Ni (Figure 24) and glass prodcution for Se (figure 25). Apart from these activities, the overall picture is comparable to the priority HM - there will hardly be remaining sources that completely dominate the emission of a certain substance.

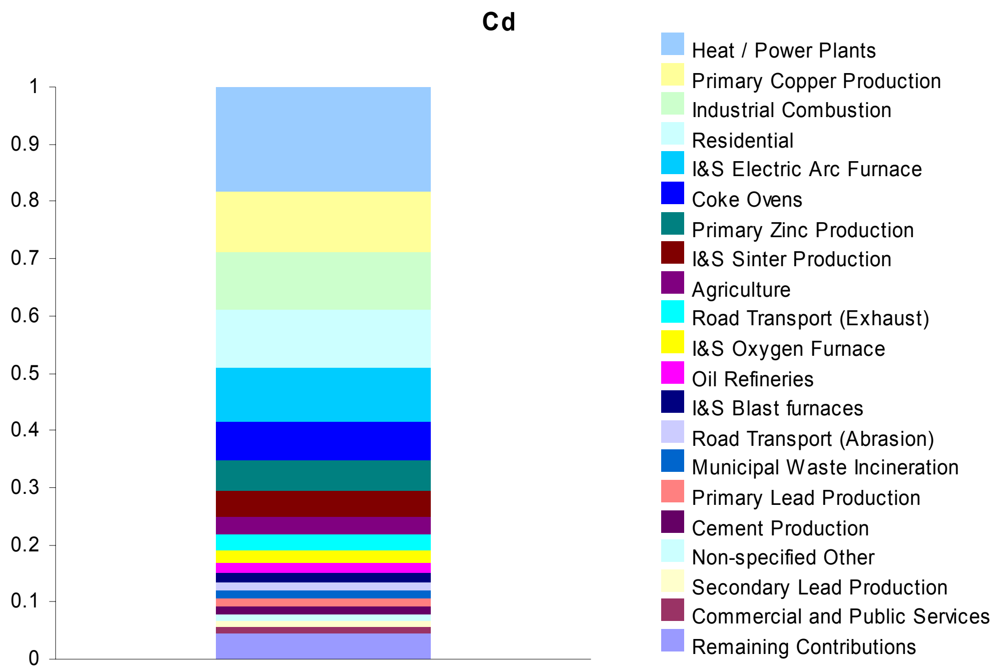


Figure 18 Remaining contributions to Cd emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

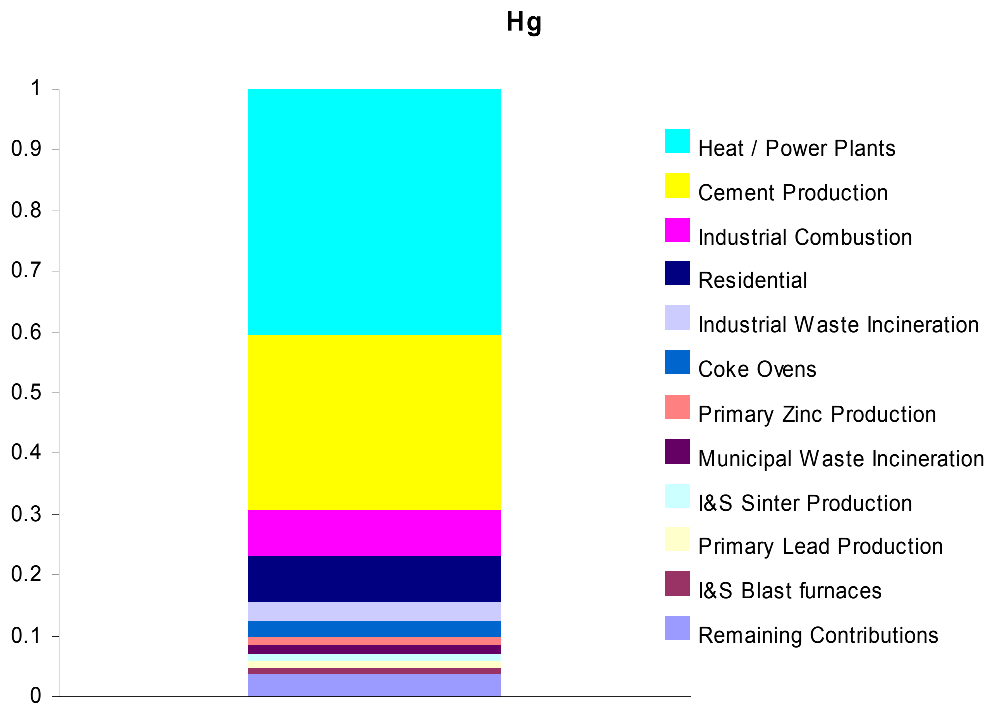


Figure 19 Remaining contributions to Hh emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

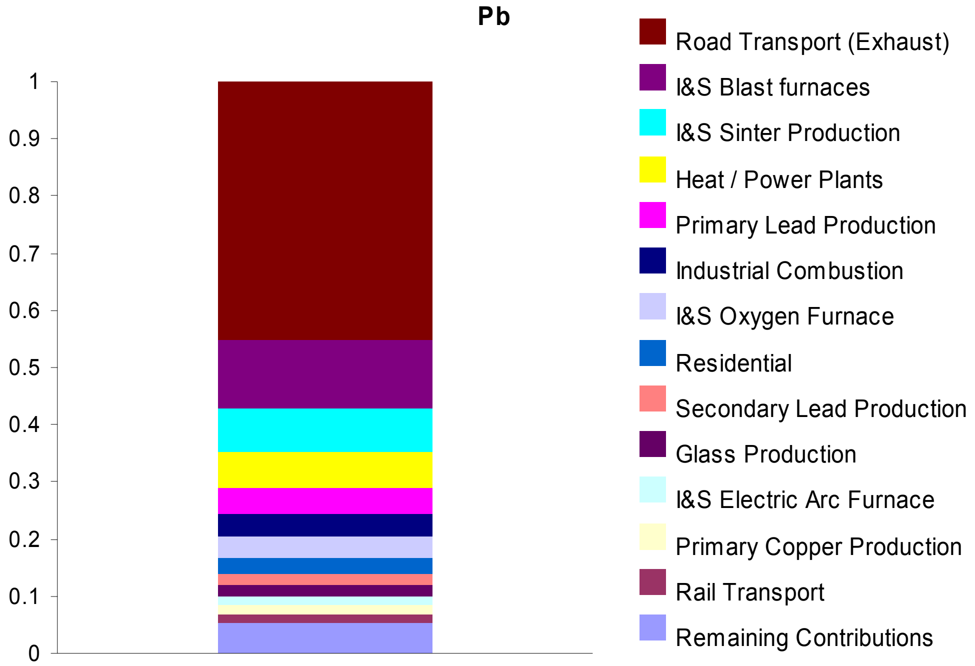


Figure 20 Remaining contributions to Pb emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

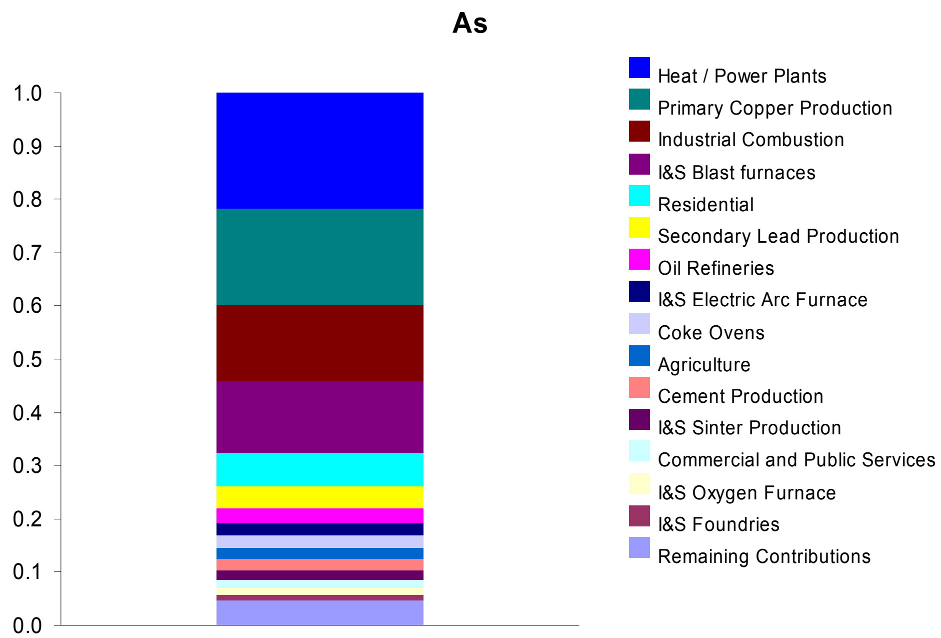


Figure 21 Remaining contributions to As emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

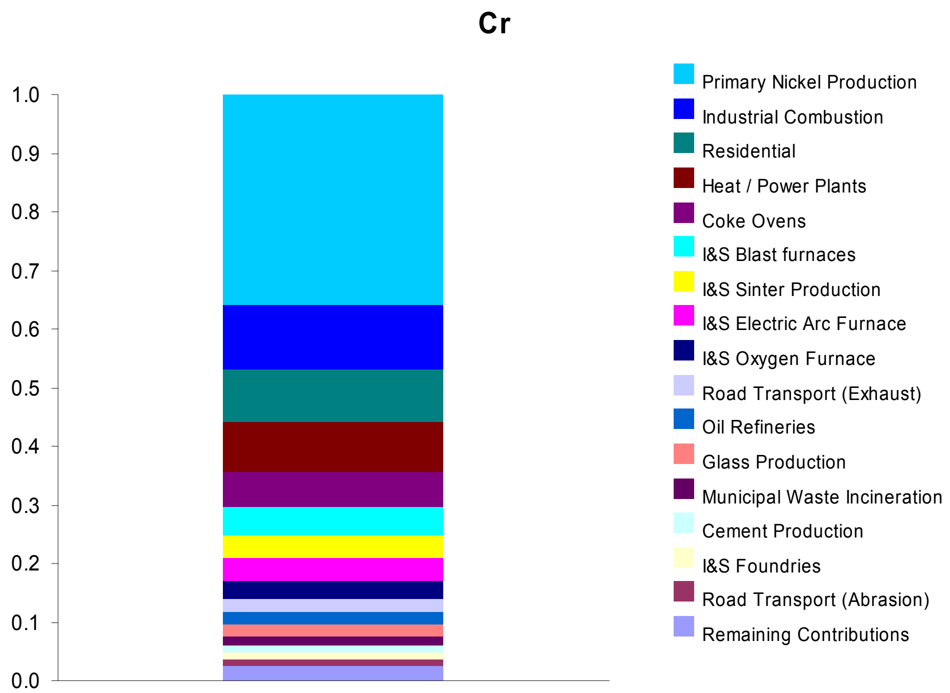


Figure 22 Remaining contributions to Cr emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

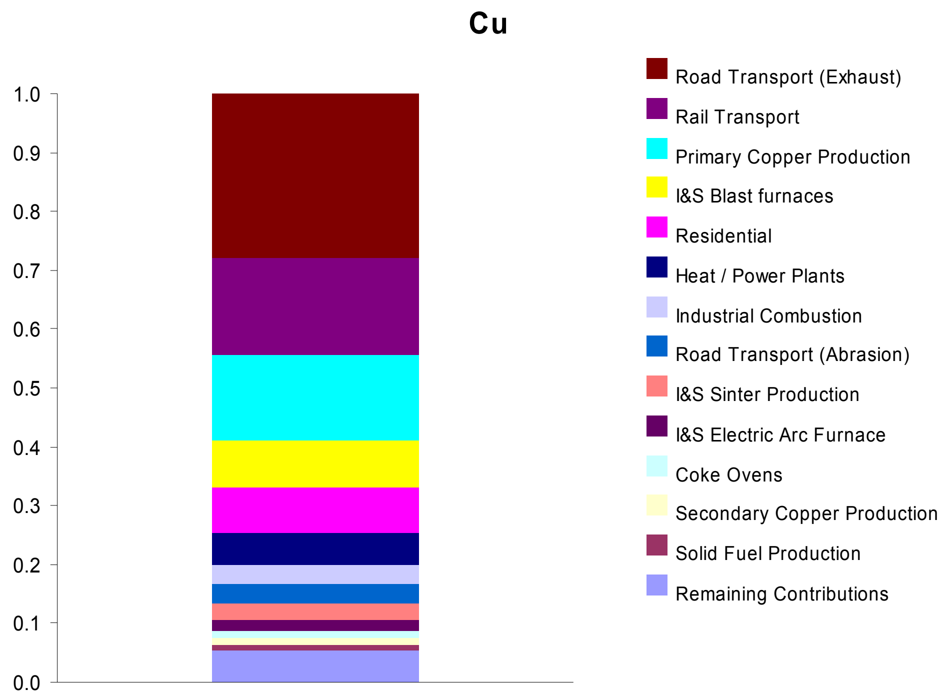


Figure 23 Remaining contributions to Cu emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

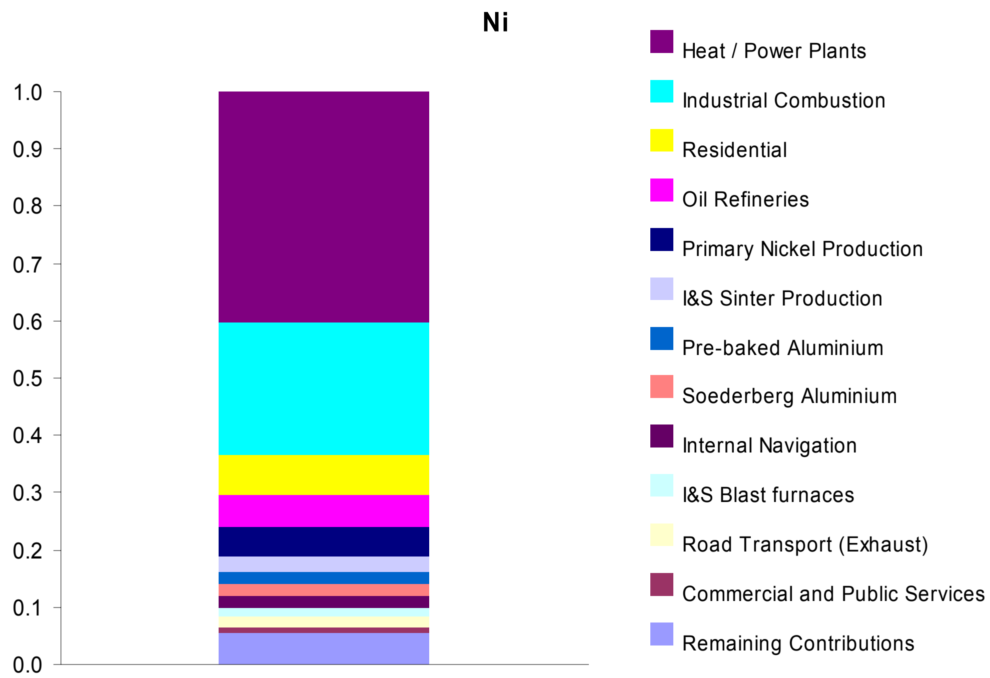


Figure 24 Remaining contributions to Ni emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

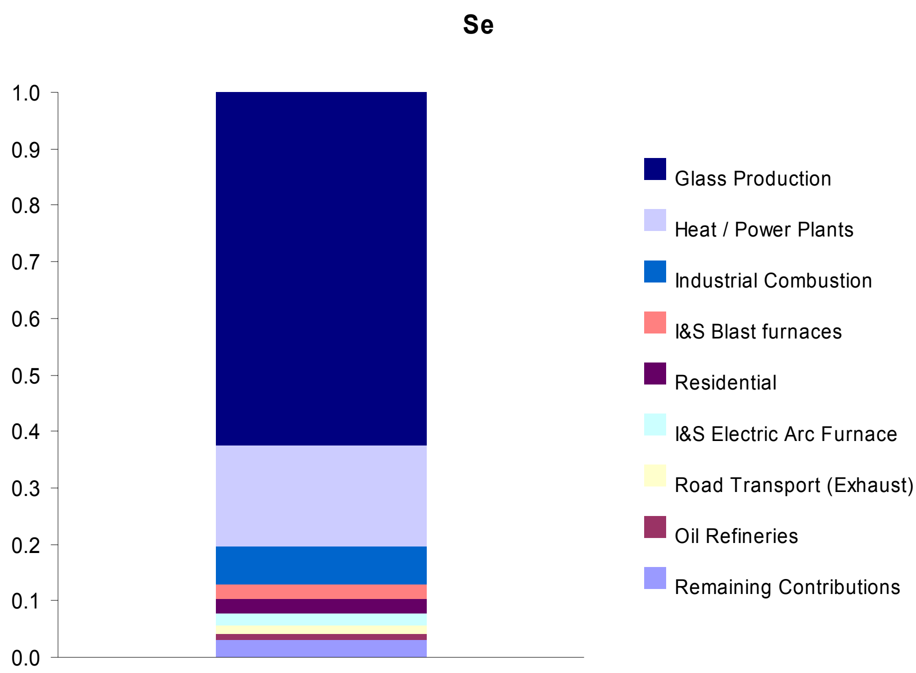


Figure 25 Remaining contributions to Se emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

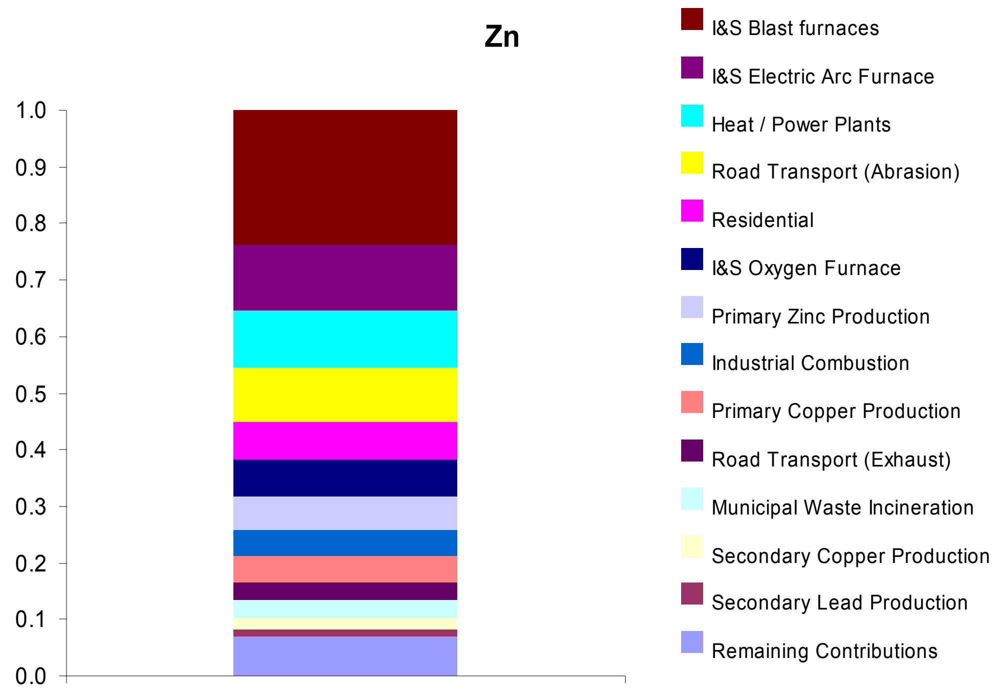


Figure 26 Remaining contributions to Zn emissions in UNECE Europe in 2020 after full implementation of the HM Protocol.

6.3 Preliminary assessment of measures to further reduce HM emissions

A first suggestion of a package of measures that may successfully achieve further reduction of HM emissions is described below on the basis of the above presented key source analysis. The assessment of options may serve as technical input to the Task Force on Heavy Metals. The measures discussed below are summarized in Table 26.

Heat / Power Plants
Heat and power plants are the most important remaining source of HM emissions. According to Figure 18, Figure 19 and Figure 20, heat and power plants have a remaining contribution of 18% for Cd, 40% for Hg and 6% for Pb. Combustion of heavy fuel oil and coal (hard coal, brown coal and peat) causes more than 95% of the Cd emission, with about equal shares. Emissions of Hg, and Pb originate for 95% and 85%, respectively, from coal use while only 5% and 10%, respectively is caused by heavy fuel oil use. For the other metals the share of heavy oil ranges from 0%, 20%, 30% and 40% for Zn, Cu, As and Se, to 75% and 95% for Cr and Ni respectively (Figure 21-Figure 26). Note that the share by fuel type is estimated by TNO and the emission factors used have a rather high uncertainty. Nevertheless

it shows heavy fuel oil use is projected to be an important contributor, next to coal use.

The current Protocol limit value is 50 mg dust/Nm^3, regardless of the type of fuel. For the combustion of heavy fuel oil this limit value can be met, provided that the fuel has a medium to low sulphur content. With high sulphur fuel oil types 50 mg/Nm^3 is easily exceeded. Reduction of sulphur content has little effect on heavy metal emission though, nor has optimization of combustion conditions. Only removal of heavy metals from the fuel or end-of-pipe particulate matter removal (by ESP, 70 – 80% PM removal efficiency attainable) could reduce emission of heavy metals.
For the combustion of coal, emission below 50 mg/Nm^3 is achieved in several European countries. In case modern flue gas desulphurization techniques are used, concentrations of 20 – 30 mg/m^3 for PM are not uncommon. Also the use of fabric filters in addition to conventional ESP achieves concentrations below the Protocol limit value. Setting a more stringent limit value could be an option for revision of the HM Protocol. For example, in the Netherlands a limit value of 20 mg/Nm^3 applies for both coal and oil-fired utilities. Heavy fuel oil is only used in installations that primarily fire coal, as an additional fuel. The BREF documents that describe the Best Available Technologies (BAT) to be applied in the European Union by 2010 as a result of the IPPC Directive mention 5 – 20 mg/Nm^3 as representative emission strength after implementation of BAT.

Road Transport (Exhaust)
Exhaust emissions from road vehicles are the most important remaining source after full implementation of the Protocol especially for lead (Figure 20). This is remarkable because so-called leaded gasoline with a lead content as was common in the 1980ties will be completely phased out by 2020 and replaced by unleaded fuel. However, the HM Protocol allows for unleaded gasoline a maximum residual lead content of 0.013 g/l. Since insufficient data are available for the actual lead content of gasoline, 0.013 g/l has been assumed in our calculations for specific countries in 2020. By doing so we may overestimate the importance of lead emissions from road transport but data are lacking. Clearly data are needed on actual lead content in fuels at the gas stations to make a better assessment of Pb emissions from road transport. Our results do show that when actual lead content in gasoline in Europe does indeed approach the 0.013 g/l, a reduction of this maximum allowable lead content would be an obvious measure to include in a revised HM Protocol.

Cement Production
Cement production is the second most important source of Hg emissions after full implementation of the protocol (Figure 19). For Cd, Pb and the other metals the contribution of cement production is not insignificant but much lower (Figure 18, Figure 20 and Figure 21-Figure 26). The results of this study are again uncertain on this issue but the high mercury emission by cement plants could be explained by two factors. Firstly, the emission control measures as a result of the HM Protocol

as well as the EU Waste Directive aim at reducing the particulate matter emission. Since Hg is largely emitted in gaseous state, this type of abatement measures has little effect on Hg. Secondly; cement producers often use various types of combustible waste as fuel to reduce production costs. Certain types of waste may contain relatively high amounts of Hg.

Further reduction of PM emission will have little effect on mercury emission and end-of-pipe techniques for Hg removal are both scarce and very expensive. A simple and effective means to reduce Hg release by cement plants would be a reduction at the start of the chain: cleaner fuels, favouring (waste) fuels with lower Hg content.

The BREF documents that describe the Best Available Technologies (BAT) to be applied in the European Union by 2010 as a result of the IPPC Directive mention 25 mg/Nm^3 as representative emission strength after implementation of BAT while the HM Protocol value is 50 mg/Nm^3.

Industrial Combustion
This source category covers the combustion of all fuels in the (manufacturing) industry sector. It includes fuel that is used in process furnaces. For this sector on the whole the type of combustion plants used is very diverse, ranging from simple 0.5 MWth units used for space heating to multiple 100 MWth-plus furnaces and boilers in the heavy industry.
Industrial combustion is a significant source of heavy metal emission for Cd, Hg and Pb. (Figure 18, Figure 19, and Figure 20). For the total of the nine metals covered by this study, industrial combustion would even rank second among the most important contributors if all HM were weighted equally (Figure 21-Figure 26). Looking at fuel types, the use of heavy fuel oil and hard coal dominates the metal release from industrial combustion. For Cu, Hg, Pb and Zn, hard coal is the more important fuel (80 – 90%) while for Cd, Cr, Ni and Se heavy fuel oils dominate (60 – 90%).

As variable as the plant capacities are the emission control measures applied. Heavy oil-fired plants are mostly uncontrolled. Coal-fired combustion units have control technologies ranging from a simple cyclone (or are uncontrolled) to multiple field ESP or fabric filters. For larger industrial plants (e.g. > 50MWth) the same view on additional control measures as mentioned in the sector about power plants holds true. In case FGD techniques are applied a concentration below 50 mg/m^3 can be achieved for a coal-fired plant. Also with the application of fabric filters 20 – 30 mg/m^3 is possible. The current Protocol only addresses combustion plants larger that 50 MWth. However, in some countries e.g., the Netherlands, also for installations smaller than 50 MWth, limit values apply. For smaller coal-fired plants various conventional techniques (cyclones, bag filters etc.) for reducing coal fly ash emission could be applied. Emission from oil-fired plants might be more diffi-

cult to control. ESP or the removal of heavy metals from the fuel prior to usage are (relatively expensive) options for larger plants to further reduce emission.
The fuel-related emission from process furnaces usually leaves through the same stack as the process emission. Abatement measures aimed at reducing process emission will hence reduce the fuel emission as well.

Residential Combustion
Residential combustion includes smaller (e.g. below 100 kW) combustion facilities mostly used for domestic space heating. Its contribution for Cd, Hg and Pb (Figure 18, Figure 19 and Figure 20) is of a similar magnitude as industrial combustion, domestic heating is also an important source for the other HM (Figure 21-Figure 26). The fuel types used in this sector differ somewhat from those used for other combustion activities. With respect to HM emission, the most important fuels are hard coal, distillate oil and wood. For about all heavy metals the use of hard coal gives the highest contri-bution (35 – 70%). Only for Ni heavy fuel oil is more important (50%) and for Hg wood is more important (60%).

Several countries in Europe have implemented regulations for new heating stoves aimed at optimizing the unit's combustion conditions. For heavy metals however these regulations have little to no effect. The most effective way to reduce HM emission would be the replacement of coal, oil and wood by natural gas. Alternative measures would have to be aimed at selecting cleaner fuels (lower HM contents) and perhaps reducing fly ash emissions by (simple) particle capturing techniques.

Blast Furnaces, Sinter Production, Oxygen, Open Hearth and Electric Arc furnaces, and Coke Ovens in the Iron and Steel Industry
The production of primary and secondary steel includes a number of processes that are projected to remain relevant to the emission of heavy metals. In our results the integrated iron and steel plant ranks among the top 3 remaining contributors for all metals except Hg (see Figure 18-Figure 26). This in spite of the fact that both the IPPC Directive and the HM Protocol address these processes (except the basic oxygen and open hearth furnace). Note that the effects of implementation of the IPPC Directive and the HM Protocol are fully accounted for in our emission inventory for 2020 with full implementation of the HM Protocol.

All processes in this industry boast high temperatures, fine particles and metal-rich raw materials. The implementation of the IPPC Directive as well as the HM Protocol will bring about a range of (largely conventional) emission abatement technologies if not already fitted. Even the more advanced technologies will remove the coarser part of fine particulate matter to a higher extent than the smaller fraction. Since some heavy metals have a tendency to accumulate in the smaller size fraction, a low particulate matter concentration is no guarantee for 'equally low' HM emissions or large reductions hereof. Thus fine particle enrichment reduces the effect of PM removal by conventional capturing techniques on HM emission. On

the other hand, if selective PM2.5 removal is anticipated in the future this would be also highly effective in removing HM. The enrichment effect is accounted for in our results, partly explaining the high remaining contribution of the iron and steel industry. Another reason for the relatively small change in contribution is the fact that in many countries the introduction of the Protocol limit values will not result in much additional effect since the limit values as they are now are already met.
Due to its relatively high remaining contribution, the current Protocol limit values might be reconsidered in the process of revising the HM Protocol. Besides the work of the Task Force on Heavy Metals, the IPPC BAT/BREF report on the iron and steel industry could serve as supporting information to investigating more stringent limit values for these processes. In all processes but especially blast furnaces and sinter plants it is possible to limit particulate matter emission of channelled gaseous release streams to concentrations below 50 mg/Nm^3. Values between 20 and 40 mg/Nm^3 can be achieved by using multiple field ESP (3 stages or wet ESP), special fabric filters (e.g. for non-adhesive dust) and advanced (high pressure) wet scrubbing (e.g. combining PCDD/F removal). Fabric filters can have excellent removal efficiency for very small particles. The BREF document on the iron and steel industry that describes the BAT, mention 5 mg/Nm^3 as representative emission strength for all processes except sinter production, after implementation of BAT. For sinter production 25 mg/m^3 is given.

In addition to adjusting existing limit values, a limit value could be introduced for basic oxygen furnaces and foundries, based on the application of fabric filters. Also for cookeries a limit value could be considered since our results indicate an important contribution for all 3 priority metals. Emission from coke ovens is partly diffuse in nature, which might hamper the definition of an emission limit. However various proven techniques aimed at reducing both door leakage and emission during coke pushing and quenching are available. Other substances like PAHs are then reduced as well with these measures.

A final remark should be made on fugitive emission sources. Our emission inventory is focussed on channelled emissions, mostly released through some kind of stack. The Protocol does not address fugitive sources. Information from the Dutch Individual Emission Registration shows however that non-channelled (diffuse) emissions of particulate matter can, in certain cases be close to equally important as stack emissions. Cookeries are already mentioned in this respect but also the transport of hot metal might be relevant. It is recommended that the metal content of certain types fugitive dust be assessed.

Primary Production of Zn, Ni, Cu and Pb; Secondary production of Pb
The last group of industrial processes that will be discussed in this context is the primary production of non-ferrous metals. In the projected Cd, Hg and Pb emissions at least one or two different processes in the primary production of non-ferrous metals make a considerable contribution to the total HM emission. Currently the production of Cu, Pb and Zn is addressed by the HM Protocol, the IPPC

Directive and to some extent the 2nd Sulphur Protocol. IPPC and the 2nd S Protocol also cover the production of Ni. Ni production is included in our calculations be-cause some plants possibly exceed the general limit value for Cd. Although there are only few Ni production sites in Europe, the related Ni and Cr emissions are highly significant (potentially accompanied by high Cd emission; see 2000 inventory results; this is not further investigated in this project). In the projection results, effects of implementation of the IPPC Directive, the HM Protocol and the 2nd Sulphur Protocol have been fully accounted for.

Zn, Ni, Cu and Pb can be produced with varying processes (e.g. thermal, electrochemical or a combination of these). This mostly depends on the raw materials, availability of power and local infrastructure. The thermal processes (e.g. for copper) are the most relevant for heavy metal emission. Like the iron and steel industry, particulate matter released to air in the non-ferrous metals production is often of relatively small size. The prevalent conventional emission control systems often enhance this by removing the coarser part to a higher extent than the finer. As explained earlier, removal of the coarser part of fine particulate is often not sufficient to decrease metal emission because of enrichment of smaller sized (and more difficult to remove) particles. In our results the metal enrichment effect (depending on volatility) of small-sized particulate is accounted for.

Its significant remaining contribution makes the non-ferrous metals industry a candidate for reconsidering existing limit values. Particulate matter concentrations in off-gasses vary by process, but generally range from 5 – 20 mg/m^3 for modern plants (e.g. in Germany). The BREF document for the non-ferrous metals industry presents 5 mg/Nm^3 as representative emission strength for all processes after implementation of BAT. Therefore, in revising the HM Protocol, limit values below the current 20 mg/Nm^3 could certainly be considered. It is recommended to use techniques that are at least as effective in removing the smaller (e.g. PM2.5) fraction as they are in the coarser (e.g. advanced fabric filters). A second option to reduce or even eliminate certain release streams would be a complete process reconstruction, avoiding thermal processes when possible, for instance through replacement by electro-chemical processes. This would almost certainly entail very high costs.

The current limit of 10 mg/Nm^3 in the HM Protocol for the production of lead could be considered reasonably stringent (although the BREF document lists 5 mg/Nm^3 as an attainable value). In addition to the process's modest contribution (Figure 20), this would rank lead production below the production of other non-ferrous metals in terms of urgency in revising the Protocol.

Table 26 Summary of potential additional reduction measures by source sectors.

Source sector	Potential additional reduction measures
Combustion of fossil fuels Capacity > 50 MWth	Coal-fired: Replacement or the limit value of 50 mg dust/m^3 by 30 mg dust/m^3 (using 3-Field-plus ESP or fabric filters; side effect of advanced FGD) Heavy fuel oil-fired: Replacement or the limit value of 50 mg dust/m^3 by 30 mg dust/m^3 (using ESP) Introduction of a maximum allowable heavy metal concentration in heavy fuel oil marketed for domestic use (by HM removal at refinery, possibly high costs)
Capacity between 5 and 50 MWth	Coal-fired: Introduction of limit value of 50 mg dust/m^3 (using ESP) Replacement of coal by natural gas Heavy oil-fired: Replacement of heavy fuel oil by natural gas Introduction of a maximum allowable heavy metal concentration in heavy fuel oil marketed for domestic use
Capacity < 5 MWth	Coal-fired: Replacement of coal by natural gas Introduction of European type approval for new coal stoves (referring to the potential to emit fly ash) Heavy and distillate oil-fired: Replacement by natural gas Introduction of a maximum allowable heavy metal concentration in heavy and medium fuel oils marketed for domestic use
Cement Production	Restriction of Hg content in waste fuel (e.g. by prohibiting the use of certain waste fuels)
Sinter plants	Replacement of current limit value of 50 mg dust/m^3 by 30 or 40 mg/m^3 (e.g. by using multiple field ESP, fabric filters or advanced high pressure scrubbing, probably considerable costs)
Blast furnaces	Replacement of current limit value of 50 mg dust/m^3 by 30 mg/m^3 (e.g. by using fabric filters)
Electric arc furnaces	Replacement of current limit value of 20 mg dust/m^3 by 10 mg/m^3 (e.g. by using fabric filters)
Basic oxygen furnaces	Introduction of emission limit value (e.g. 10 or 20 mg dust/m^3 by using fabric filters)
Open hearth furnaces	Elimination (obsolete technology)
Coke ovens	Introduction of a maximum allowable metal content in coke oven gas used to fire the oven (e.g. by thorough dedusting before use) Introduction of a limit value for gaseous release streams during cooking, pushing and quenching of coke (e.g. 50 mg dust/m^3 by using ESP or wet scrubbing) Minimizing door leakage (e.g. by prescribing the use of special door sealing)
Production of copper and zinc, including Imperial Smelting	Replacement of current limit value of 20 mg dust/m^3 by 10 mg/m^3 (e.g. by using fabric filters) Elimination of obsolete thermally-based production processes when possible (high cost)
Product management	Lowering the maximum allowable Pb content of gasoline (e.g. from 0.013 g/l to 0.005 g/l)

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Annex 2 Grouping of countries within UNECE-Europe based on ratified protocols by country and obligations to EU directives

CountryGroupID	CountryID	HM Protocol	EU25	2nd S protocol
HM Protocol	AUT	x	x	x
	BGR	x		
	CHE	x		x
	CYP	x	x	
	CZE	x	x	x
	DEU	x	x	x
	DNK	x	x	x
	FIN	x	x	x
	FRA	x	x	x
	HUN	x	x	x
	LTU	x	x	
	LUX	x	x	x
	LVA	x	x	
	MDA	x		
	NLD	x	x	x
	NOR	x		x
	ROM	x		
	SVK	x	x	x
	SVN	x	x	x
	SWE	x	x	x
EU25 a/o 2nd S Protocol	BEL		x	x
(no HM Protocol)	ESP		x	x
	EST		x	
	GBR		x	x
	GRC		x	x
	HRV			x
	IRL		x	x
	ITA		x	x
	POL		x	
	PRT		x	
Other	ALB			
	ARM			
	AZE			
	BIH			
	BLR			
	GEO			
	ISL			
	KAZ			
	KGZ			

CountryGroupID	CountryID	HM Protocol	EU25	2nd S protocol
	MKD			
	RUS			
	TUR			
	UKR			
	YUG			

Annex 3 Activities considered as sources of HM and/or POP in this study

CRFSubID[1)]	Description	CRF/NFR[2)] Code	Common Format[3)]
3	Public Electricity Plants	1.A.1.a	1_PHP
4	Autoproducer Electricity Plants	1.A.1.a	1_PHP
5	Public CHP Plants	1.A.1.a	1_PHP
6	Autoproducer CHP Plants	1.A.1.a	1_PHP
7	Public Heat Plants	1.A.1.a	1_PHP
8	Autoproducer Heat Plants	1.A.1.a	1_PHP
10	Coke Ovens	2.C.1.4	3_IND
14	Coal Mines	1.A.1	3_IND
15	Oil and Gas Extraction	1.A.1	3_IND
16	Patent Fuel Plants	1.A.1.c	3_IND
17	BKB Plants	1.A.1.c	3_IND
18	Oil Refineries	1.A.1.b	3_IND
19	Own Use in Electricity, CHP and Heat Plants	1.A.1.a	1_PHP
20	Iron and Steel	1.A.2.a	3_IND
21	Chemical and Petrochemical	1.A.2.c	3_IND
22	Non-Ferrous Metals	1.A.2.b	3_IND
23	Non-Metallic Minerals	1.A.2.f	3_IND
24	Transport Equipment	1.A.2.f	3_IND
25	Machinery	1.A.2.f	3_IND
26	Mining and Quarrying	1.A.1	3_IND
27	Food and Tobacco	1.A.2.e	3_IND
28	Paper, Pulp and Printing	1.A.2.d	3_IND
29	Wood and Wood Products	1.A.2.f	3_IND
30	Construction	1.A.2.f	3_IND
31	Textile and Leather	1.A.2.f	3_IND
32	Non-specified Industry	1.A.2.f	3_IND
34	Domestic Air Transport	1.A.3.a	6_NRT
35	Road	1.A.3.b.v	5_ROT
36	Rail	1.A.3.c	6_NRT
37	Pipeline Transport	1.A.3.e.i	6_NRT
38	Internal Navigation	1.A.3.d.ii	6_NRT
39	Non-specified Transport	1.A.3.e	6_NRT
40	Agriculture	1.A.4.c	2_RCO
41	Commercial and Public Services	1.A.4.a	2_RCO
42	Residential	1.A.4.b.i	2_RCO
43	Non-specified Other	1.A.5	2_RCO

CRFSubID[1)]	Description	CRF/NFR[2)] Code	Common Format[3)]
45	Basic Oxygen Furnace	2.C.1.1	3_IND
46	Electric Arc Furnace	2.C.1.1	3_IND
47	Open Hearth Furnace	2.C.1.1	3_IND
48	Blast furnaces	2.C.1.2	3_IND
51	HDV highway	1.A.3.b.iii	5_ROT
52	HDV rural	1.A.3.b.iii	5_ROT
53	HDV urban	1.A.3.b.iii	5_ROT
54	LDV highway	1.A.3.b.ii	5_ROT
55	LDV rural	1.A.3.b.ii	5_ROT
56	LDV urban	1.A.3.b.ii	5_ROT
57	PC highway	1.A.3.b.i	5_ROT
58	PC rural	1.A.3.b.i	5_ROT
59	PC urban	1.A.3.b.i	5_ROT
60	MC highway	1.A.3.b.iv	5_ROT
61	MC rural	1.A.3.b.iv	5_ROT
62	MC urban	1.A.3.b.iv	5_ROT
91	Sinter Production	2.C.1.3	3_IND
94	Chlorine	2.B.5	3_IND
100	Cement	2.A.1	3_IND
101	Pig iron, foundry	2.C.1.5	3_IND
102	Copper, primary, refined_FPRIM	2.C.5	3_IND
103	Copper, secondary, refined_FSEC	2.B.5	3_IND
104	Copper, secondary, refined_SLR	2.A.1	3_IND
105	Copper, secondary, refined_SR	2.C.5	3_IND
106	Copper, secondary, refined_SRE	2.C.5	3_IND
107	Copper, secondary, refined_SRT	2.C.5	3_IND
108	Nickel, unwrought_X	2.C.5	3_IND
109	Aluminium, unwrought, pri-mary_shs	2.C.3	3_IND
110	Aluminium, unwrought, primary_sp	2.C.3	3_IND
111	Aluminium, unwrought, pri-mary_svs	2.C.3	3_IND
112	Aluminium, unwrought, secondary	2.C.3	3_IND
113	Lead, primary, refined soft_PFISF	2.C.5	3_IND
114	Lead, primary, refined soft_PFKV	2.C.5	3_IND
115	Lead, primary, refined soft_PRE1	2.C.5	3_IND
116	Lead, primary, refined soft_PRT1	2.C.5	3_IND
117	Lead, secondary, refined soft_SRT1_2	2.C.5	3_IND
118	Lead, secondary, refined soft_SRT2	2.C.5	3_IND
120	Zinc, unwrought, primary_PCH	2.C.5	3_IND
121	Zinc, unwrought, primary_PE	2.C.5	3_IND

CRFSubID[1)]	Description	CRF/NFR[2)] Code	Common Format[3)]
122	Zinc, unwrought, primary_PISF	2.C.5	3_IND
123	Zinc, unwrought, primary_PISFRT	2.C.5	3_IND
124	Zinc, unwrought, primary_PRTZN	2.C.3	3_IND
125	Zinc, unwrought, primary_SCV	2.C.5	3_IND
130	Glass, drawn or blown, in rectangles, unworked	2.C.5	3_IND
131	Glass, cast, rolled, drawn or blown	2.C.5	3_IND
132	Glass fibres (including glass wool)	2.C.5	3_IND
133	Toughened or laminated safety glass	2.C.5	3_IND
134	Glass bottles and other containers of common glass	2.C.5	3_IND
135	Municipal waste incineration	6.C	7_WAS
136	Hospital waste incineration	6.C	7_WAS
137	Industrial waste incineration	6.C	7_WAS
138	Hazardeous waste incineration	6.C	7_WAS
139	Lead from Road	1.A.3.b	5_ROT
140	Creosoot	1.A.2	4_SPU
141	PCB_transformers	-	4_SPU
142	PCB_large_capacitors	-	4_SPU
143	PCB_small_capacitors	-	4_SPU
144	Cremation	-	7_WAS
147	Fungicide use	-	4_SPU

1) CRFsubID = Common Reporting Format sub activity IDentification number

2) Common Reporting Format / Nomenclature For Reporting

3) see Table 4, page 18

Annex 4 Emissions of Heavy metals in UNECE_Europe by source sector per country for the year 2000[1]

Annual emissions of heavy metals in Albania per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*13*	*4*	*23*	*14*	*32*	*13*	*624*	*12*	*3*
Residential, commercial and other	*69*	*110*	*309*	*29*	*236*	*279*	*1089*	*20*	*2069*
Industry	*108*	*85*	*531*	*130*	*266*	*255*	*4089*	*87*	*889*
Solvent and product use									
Road transport	*5*		*42118*		*24*	*619*	*31*	*3*	*1151*
Non-Road transport	*0*	*1*	*106*	*1*	*1*	*10*	*2*	*5*	*17*
Waste disposal	*3*	*3*	*97*	*0*	*1*	*1*	*0*	*0*	*16*
Agriculture									
Total	**199**	**203**	**43183**	**175**	**560**	**1176**	**5835**	**127**	**4144**

Annual emissions of heavy metals in Armenia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*0*		*0*		*0*	*0*	*0*		*0*
Residential, commercial and other	*36*	*79*	*206*	*4*	*135*	*193*	*25*	*0*	*1580*
Industry	*89*	*82*	*207*	*92*	*231*	*84*	*4098*	*152*	*98*
Solvent and product use									
Road transport	*1*		*7750*		*4*	*51*	*4*	*0*	*308*
Non-Road transport						*224*			
Waste disposal	*4*	*3*	*110*	*0*	*1*	*1*	*0*	*0*	*18*
Agriculture									
Total	**129**	**164**	**8274**	**96**	**371**	**553**	**4127**	**153**	**2004**

Annual emissions of heavy metals in Austria per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	169	292	796	*469*	*797*	*411*	*11397*	*463*	*4095*
Residential, commercial and other	547	248	4668	*355*	*2196*	*3243*	*7947*	*152*	*18743*
Industry	619	597	8279	*1930*	*7379*	*9933*	*23026*	*1143*	*129445*
Solvent and product use	0	0	24						
Road transport	77	1	11		*433*	*10812*	*542*	*57*	*23521*
Non-Road transport	1	0	3	*5*	*5*	*7501*	*7*	*2*	*96*
Waste disposal	3	10	10	*35*	*521*	*695*	*139*	*9*	*11808*
Agriculture	12	2	62						
Total	**1427**	**1151**	**13853**	**2794**	**11331**	**32595**	**43058**	**1826**	**187707**

1) Shaded Italics indicate TNO Reference estimates

Annual emissions of heavy metals in Azerbaijan per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	2040	649	3524	2114	5008	1947	96445	1860	408
Residential, commercial and other	107	175	486	42	362	434	1575	30	3310
Industry	115	154	315	118	239	110	4036	145	156
Solvent and product use									
Road transport	20		5796		79	850	83	3	7630
Non-Road transport	1	0	1921	10	7	1424	337	5	103
Waste disposal	7	6	221	0	2	2	0	0	36
Agriculture									
Total	**2291**	**984**	**12263**	**2285**	**5697**	**4767**	**102477**	**2043**	**11643**

Annual emissions of heavy metals in Belgium per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	40	490	640	230	680	520	16660	820	3030
Residential, commercial and other	140	130	1400	300	200	310	360	30	1390
Industry	2250	1380	111230	3150	23290	12650	34970	3380	144300
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	90	0	18620	0	430	13030	580	70	15370
Non-Road transport	10	0	10	10	0	10	10	0	0
Waste disposal	220	260	1900	150	350	330	110	20	2240
Agriculture	0	0	0	0	0	0	0	0	0
Total	**2750**	**2260**	**133800**	**3840**	**24950**	**26850**	**52690**	**4320**	**166330**

Annual emissions of heavy metals in Bulgaria per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	615	1513	3615	2373	1438	9414	6373	656	65953
Residential, commercial and other	188	255	385	61	459	608	1086	18	4210
Industry	9874	1951	142126	1032	4976	4450	18791	11693	54537
Solvent and product use	0	0	0						
Road transport	11	0	65081		86	2524	113	14	3532
Non-Road transport	6	0	784	3	3	1595	34	1	60
Waste disposal	292	467	2152	6	84	111	22	1	1893
Agriculture									
Total	**10986**	**4186**	**214143**	**3474**	**7045**	**18703**	**26420**	**12384**	**130186**

Annual emissions of heavy metals in Bosnia and Herzegovina per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	1200	1496	27973	1968	847	6608	3968	848	59450
Residential, commercial and other	196	278	1032	168	758	994	2054	28	4727
Industry	269	206	1057	101	108	555	1001	2	3430
Solvent and product use									
Road transport	7		66667		33	905	43	5	1295
Non-Road transport	1	0	124	3	3	104	4	0	61
Waste disposal	2	2	68	0	0	1	0	0	11
Agriculture									
Total	**1675**	**1982**	**96921**	**2239**	**1749**	**9166**	**7070**	**883**	**68974**

Annual emissions of heavy metals in Belarus per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	94	24	2322	602	1002	915	77415	885	3547
Residential, commercial and other	28	6	418	589	331	1376	1092	61	4301
Industry	1241	326	41920	2139	4889	9049	15192	4498	188492
Solvent and product use									
Road transport	15	0	1461	0	73	438	731	16	146
Non-Road transport	6	5	4619	30	11	2691	16	2	233
Waste disposal	10	2	299	0	2	3	1	0	49
Agriculture									
Total	**1394**	**363**	**51039**	**3360**	**6308**	**14472**	**94446**	**5462**	**196768**

Annual emissions of heavy metals in Switzerland per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	100	30	500	1	0	1	0	0	300
Residential, commercial and other	300	100	1200	226	223	427	134	5	1800
Industry	1100	1100	52200	432	959	508	6292	221	155300
Solvent and product use	0	0	0						0
Road transport	76	0	4369		322	9119	417	48	309987
Non-Road transport	0	0	19000	6	6	8911	9	2	2900
Waste disposal	600	1400	36300	134	2006	2675	535	35	88000
Agriculture	0	0	0						0
Total	**2176**	**2630**	**113569**	**798**	**3518**	**21641**	**7388**	**311**	**558287**

Annual emissions of heavy metals in Cyprus per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	477	152	162	495	1169	456	22514	434	98
Residential, commercial and other	7	14	39	1	25	36	25	0	288
Industry	82	427	751	133	358	177	2598	81	1539
Solvent and product use									
Road transport	6		73000		28	945	39	6	556
Non-Road transport									
Waste disposal	1	1	22	0	0	0	0	0	4
Agriculture									
Total	**572**	**593**	**73973**	**629**	**1580**	**1614**	**25176**	**521**	**2484**

Annual emissions of heavy metals in Czech Republic per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	320	330	1870	8160	3141	13143	16578	4073	139360
Residential, commercial and other	40	640	1380	532	2239	5366	6021	300	14075
Industry	1860	1950	28840	2898	10454	12970	24068	11361	143587
Solvent and product use									
Road transport	30	0	69000		250	7301	330	40	10070
Non-Road transport	10	0	10	7	7	4200	10	2	138
Waste disposal	580	920	6610	36	542	722	144	9	12276
Agriculture									
Total	**2840**	**3840**	**107710**	**11634**	**16633**	**43703**	**47151**	**15785**	**319506**

Annual emissions of heavy metals in Germany per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	1056	16101	13742	14405	10409	4524	31861	9166	122204
Residential, commercial and other	2149	1490	11268	1804	3904	7052	6647	177	25382
Industry	14976	16218	534656	17260	40311	84910	199874	20093	961801
Solvent and product use									
Road transport	882		397		3996	102940	5046	544	209760
Non-Road transport	11	14	11686	58	54	53976	79	61	997
Waste disposal	1987	22190	15894	993	14899	19866	3973	258	337723
Agriculture									
Total	**21062**	**56014**	**587643**	**34520**	**73574**	**273268**	**247481**	**30299**	**1657867**

Annual emissions of heavy metals in Denmark per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	313	1582	3373	484	1230	1064	3969	919	12247
Residential, commercial and other	133	209	365	82	113	182	1424	192	2232
Industry	234	245	2197	246	827	330	6904	788	3130
Solvent and product use									
Road transport	35		58		178	6038	249	35	3552
Non-Road transport	12	16	1522	33	61	1458	1186	83	1020
Waste disposal	*257*	*2873*	*2059*	*129*	*1930*	*2574*	*515*	*33*	*43758*
Agriculture									
Total	**986**	**4925**	**9574**	**974**	**4340**	**11646**	**14246**	**2050**	**65940**

Annual emissions of heavy metals in Spain per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	4214	5508	6538	5417	13171	10410	142334	4520	24066
Residential, commercial and other	245	137	868	425	593	425	748	245	216
Industry	10493	15715	265432	49982	19645	81904	101575	55476	644117
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	*400*	0	*657133*	0	*1820*	*47615*	*2311*	*254*	*92381*
Non-Road transport	63	31	110	175	323	8439	9365	268	5383
Waste disposal	106	397	2016	73	377	751	154	18	23391
Agriculture	0	0	0	0	0	0	0	0	0
Total	**15521**	**21788**	**932097**	**56072**	**35929**	**149544**	**256487**	**60781**	**789554**

Annual emissions of heavy metals in Estonia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	550	523	31855	9326	8527	2129	6080	*61*	43624
Residential, commercial and other	102	14	3582	145	884	194	1338	*25*	7437
Industry	22	16	925	197	243	58	402	*904*	1255
Solvent and product use	0	0	0	0	0	0	0		0
Road transport	5	0	4368	0	28	951	39	*5*	559
Non-Road transport	1	0	0	0	4	150	6	*2*	88
Waste disposal	0	0	0	0	0	0	0	*0*	0
Agriculture	0	0	0	0	0	0	0		0
Total	**680**	**553**	**40730**	**9668**	**9686**	**3482**	**7865**	**996**	**52963**

Annual emissions of heavy metals in Finland per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	100	200	3000	600	1000	1500	4800	*724*	7000
Residential, commercial and other	200	0	9600	200	2000	2700	3700	*100*	8400
Industry	1100	300	24900	3700	25000	14500	24700	*4514*	55200
Solvent and product use	0	0	0	0	0	0	0		0
Road transport	0	0	0	0	0	0	0	*36*	0
Non-Road transport	0	0	0	0	0	0	0	*35*	0
Waste disposal	0	0	0	0	0	0	0	*83*	0
Agriculture	0	0	0	0	0	0	0		0
Total	**1400**	**500**	**37500**	**4500**	**28000**	**18700**	**33200**	**5491**	**70600**

Annual emissions of heavy metals in France per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	2040	5130	23690	1260	3430	5780	46760	430	177620
Residential, commercial and other	472	413	28211	3080	14735	9963	17635	2271	90868
Industry	6696	5688	154772	20677	239817	22281	154659	11548	1121954
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	0	0	14462	0	0	81670	0	0	0
Non-Road transport	3	2	130	4	17	53112	683	6	204
Waste disposal	1242	2142	12832	243	1393	4359	1942	7	50795
Agriculture	0	0	0	0	0	0	0	0	0
Total	**10453**	**13375**	**234098**	**25264**	**259392**	**177165**	**221679**	**14262**	**1441441**

Annual emissions of heavy metals in United Kingdom per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	398	1612	18406	4417	14920	13994	12413	14188	11269
Residential, commercial and other	315	674	15694	7782	3505	5199	24471	3518	7784
Industry	5483	4295	133304	25634	50393	27793	85270	10750	379291
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	373	2	20972	0	370	584	1324	370	10070
Non-Road transport	21	1	413	2	38	58	1573	24	58
Waste disposal	658	2210	4051	188	129	556	236	0	4711
Agriculture	0	0	0	0	0	0	0	0	0
Total	**7249**	**8793**	**192842**	**38022**	**69354**	**48183**	**125288**	**28849**	**413184**

Annual emissions of heavy metals in Georgia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	107	39	328	118	260	129	4949	100	315
Residential, commercial and other	78	121	400	34	243	335	638	13	2449
Industry	13	88	63	13	29	9	212	4	81
Solvent and product use									
Road transport	6		5922		28	856	37	5	834
Non-Road transport	1	0	3	8	3	1503	510	7	15
Waste disposal	5	4	158	0	1	2	0	0	26
Agriculture									
Total	**210**	**253**	**6874**	**173**	**563**	**2834**	**6346**	**129**	**3720**

Annual emissions of heavy metals in Greece per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	1222	2222	4844	2226	3134	4096	42812	802	21747
Residential, commercial and other	272	217	1229	190	472	704	1135	17	4533
Industry	1212	4153	8157	1399	30860	2100	47987	947	26407
Solvent and product use									
Road transport	88		116678		394	9848	492	51	21894
Non-Road transport	28	18	899	158	93	1400	7145	148	970
Waste disposal	22	41	631	1	21	28	6	0	478
Agriculture									
Total	**2844**	**6650**	**132437**	**3975**	**34975**	**18177**	**99577**	**1965**	**76028**

Annual emissions of heavy metals in Croatia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	91	118	476	321	1275	556	6189	469	869
Residential, commercial and other	201	166	283	66	218	273	1087	16	2293
Industry	595	118	3569	681	2321	1293	18764	131	7847
Solvent and product use									
Road transport	126		136480		474	6985	478	13	49571
Non-Road transport	4	1	6062	0	22	677	28	4	400
Waste disposal	2	7	37	0	2	4	4	0	79
Agriculture									
Total	**1019**	**410**	**146907**	**1068**	**4312**	**9788**	**26550**	**633**	**61059**

Annual emissions of heavy metals in Hungary per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	587	977	1110	938	1563	771	22160	750	1158
Residential, commercial and other	273	544	4334	2067	1543	2065	3089	289	1707
Industry	772	1631	11200	2686	2794	3595	4941	504	17256
Solvent and product use									
Road transport	1044	0	16830	0	490	8442	6974	49	13973
Non-Road transport	*2*	*1*	*1705*	*8*	*4*	*3501*	*6*	*1*	*84*
Waste disposal	71	1044	3480	17	267	356	71	29	6052
Agriculture									
Total	**2748**	**4197**	**38659**	**5717**	**6661**	**18731**	**37241**	**1621**	**40231**

Annual emissions of heavy metals in Ireland per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*563*	*579*	*1505*	*932*	*1672*	*677*	*26533*	*901*	*1556*
Residential, commercial and other	*302*	*213*	*2024*	*351*	*916*	*1697*	*5845*	*169*	*771*
Industry	*413*	*793*	*2532*	*447*	*960*	*288*	*12930*	*298*	*6039*
Solvent and product use									
Road transport	*44*		*20*		*204*	*5596*	*263*	*31*	*9224*
Non-Road transport	*2*	*1*	*2544*	*19*	*13*	*359*	*642*	*13*	*182*
Waste disposal	*16*	*177*	*127*	*8*	*119*	*159*	*32*	*2*	*2704*
Agriculture									
Total	**1341**	**1763**	**8754**	**1757**	**3884**	**8776**	**46246**	**1414**	**20476**

Annual emissions of heavy metals in Iceland per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Residential, commercial and other	*23*	*10*	*77*	*20*	*37*	*37*	*406*	*8*	*167*
Industry	*55*	*81*	*105*	*72*	*186*	*35*	*3041*	*40*	*1792*
Solvent and product use									
Road transport	*2*		*2*		*9*	*323*	*13*	*2*	*190*
Non-Road transport	*0*	*0*	*1*	*1*	*1*	*17*	*31*	*1*	*12*
Waste disposal	*2*	*18*	*13*	*1*	*12*	*16*	*3*	*0*	*275*
Agriculture									
Total	**81**	**109**	**197**	**94**	**246**	**428**	**3495**	**51**	**2436**

Annual emissions of heavy metals in Italy per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	174	1073	3634	2854	16285	6314	26375	2810	5214
Residential, commercial and other	1560	1057	4417	637	1809	3055	44275	46	11087
Industry	8636	7411	205508	38983	26698	43412	30948	87979	1404914
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	40	0	677358	0	101	2590	197	592	1040
Non-Road transport	5	10	2847	26	24	15383	36	42	411
Waste disposal	635	605	15145	118	1289	1674	6079	11	8200
Agriculture	0	0	0	0	0	0	0	0	0
Total	**11051**	**10156**	**908909**	**42619**	**46207**	**72426**	**107911**	**91478**	**1430867**

Annual emissions of heavy metals in Kazakhstan per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	4814	9511	226397	14433	5246	45460	24418	7047	451828
Residential, commercial and other	338	574	1819	111	1030	1501	403	7	11725
Industry	13951	6942	335472	29226	25928	159053	64650	4155	559893
Solvent and product use									
Road transport	16		29665		82	2793	115	16	1643
Non-Road transport	105	1	7028	48	96	9424	1891	28	1063
Waste disposal	15	12	460	0	3	4	1	0	75
Agriculture									
Total	**19239**	**17042**	**600841**	**43818**	**32385**	**218235**	**91478**	**11253**	**1026227**

Annual emissions of heavy metals in Kyrgyzstan per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	87	181	4330	271	87	866	199	130	8660
Residential, commercial and other	125	178	503	62	409	444	2621	50	3237
Industry	130	255	2334	143	347	587	600	113	5141
Solvent and product use									
Road transport	2		53911		8	272	11	2	160
Non-Road transport	0	0		2	2	235	3	0	39
Waste disposal	4	4	135	0	1	1	0	0	22
Agriculture									
Total	**347**	**618**	**61214**	**478**	**854**	**2405**	**3435**	**294**	**17259**

Annual emissions of heavy metals in Lithuania per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	374	7	486	374	935	374	13097	*184*	374
Residential, commercial and other	517	245	784	401	776	572	10143	*48*	5125
Industry	53	*215*	890	7	33	*225*	12	*1410*	6419
Solvent and product use									
Road transport	403		12303		566	5052	2910	*8*	49351
Non-Road transport	4	*0*	1454	*4*	*4*	400	400	*1*	545
Waste disposal	*16*	*135*	*204*	*6*	*91*	*121*	*24*	*2*	*2063*
Agriculture									
Total	**1367**	**603**	**16121**	**792**	**2405**	**6745**	**26586**	**1653**	**63877**

Annual emissions of heavy metals in Luxembourg per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	0	0	*0*	0	0	1	2	0	1
Residential, commercial and other	20	2	*82*	12	36	49	204	0	97
Industry	26	272	*2704*	54	279	348	438	18	35104
Solvent and product use	0	0		0	0	0	0	0	0
Road transport	5	0	*8*	0	23	769	32	5	452
Non-Road transport	1	*0*	*475*	9	3	84	4	1	55
Waste disposal	0	1	*99*	4	1	1	0	1	987
Agriculture	0	0		0	0	0	0	0	0
Total	**51**	**275**	**3368**	**79**	**342**	**1252**	**680**	**24**	**36697**

Annual emissions of heavy metals in Latvia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	230	82	412	246	571	227	10892	210	70
Residential, commercial and other	0	0	0	0	0	0	0	0	0
Industry	352	67	6379	377	5130	2844	72	210	55825
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	6	0	1438	0	30	1024	42	6	603
Non-Road transport	0	0	0	0	0	0	0	0	0
Waste disposal	0	0	0	0	0	0	0	0	0
Agriculture	0	0	0	0	0	0	0	0	0
Total	**589**	**148**	**8230**	**624**	**5731**	**4095**	**11006**	**427**	**56498**

Annual emissions of heavy metals in Republic of Moldova per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	94	106	158	57	241	107	3289	*49*	*1895*
Residential, commercial and other	56	20	822	394	312	715	865	*14*	*2770*
Industry	14	15	32	22	42	26	444	*1643*	*10989*
Solvent and product use	0	0	0	0	0	0	0		
Road transport	3	0	2144	0	16	536	309	*1*	*830*
Non-Road transport	201	*0*	0	0	5	182	774	*0*	*11*
Waste disposal	0	0	0	0	0	0	0	*0*	*21*
Agriculture	5	5	11	4	10	7	178		
Total	**373**	**146**	**3167**	**477**	**626**	**1573**	**5859**	**1707**	**16515**

Annual emissions of heavy metals in Former Yugoslav Republic of Macedonia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*987*	*557*	*1942*	*475*	*565*	*1843*	*6236*	*114*	*8644*
Residential, commercial and other	*37*	*50*	*152*	*21*	*117*	*129*	*744*	*14*	*900*
Industry	*8734*	*1235*	*39395*	*264*	*575*	*832*	*2505*	*106*	*429119*
Solvent and product use									
Road transport	*4*		*45333*		*21*	*572*	*27*	*3*	*962*
Non-Road transport	*0*	*0*	*83*	*0*	*0*	*73*	*0*	*0*	*4*
Waste disposal	*2*	*2*	*58*	*0*	*0*	*1*	*0*	*0*	*10*
Agriculture									
Total	**9764**	**1843**	**86962**	**760**	**1279**	**3450**	**9511**	**237**	**439638**

Annual emissions of heavy metals in Netherlands per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	50	88	499	223	258	270	808	*1343*	1020
Residential, commercial and other	64	25	2630	13	27	2968	633	*7*	5041
Industry	996	310	39661	765	3325	3749	40094	*695*	63340
Solvent and product use	0	0	0	0	0	0	0		0
Road transport	37	0	248	230	1851	2044	1142	*88*	33711
Non-Road transport	6	13	1025	16	92	6493	10460	*132*	298
Waste disposal	6	142	7	11	5	12	24	*69*	35
Agriculture	0	0	0	0	0	0	0		0
Total	**1158**	**578**	**44070**	**1258**	**5558**	**15537**	**53161**	**2334**	**103445**

Annual emissions of heavy metals in Norway per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	35	37	411	38	118	215	*7*	*4*	*1103*
Residential, commercial and other	123	141	131	221	230	589	*95*	*2*	*2823*
Industry	456	548	3406	1923	7782	4227	*55549*	*305*	*29111*
Solvent and product use	0	42	0	0	0	0			
Road transport	69	64	259	139	549	12702	*201*	*29*	*2968*
Non-Road transport	20	88	1796	101	100	1518	*512*	*137*	*576*
Waste disposal	3	58	23	4	5	9	*296*	*19*	*25195*
Agriculture	20	20	10	31	30	70			
Total	**725**	**996**	**6035**	**2457**	**8814**	**19329**	**56660**	**496**	**61777**

Annual emissions of heavy metals in Poland per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	2900	10200	27100	5800	7600	21400	39700	*7787*	81100
Residential, commercial and other	27900	2800	156400	17900	22700	96100	130300	*1467*	620400
Industry	18700	12000	415800	26700	51500	253400	76500	*32509*	1467500
Solvent and product use	0	0	0	0	0	0	0		0
Road transport	200	0	38100	0	2500	2600	4400	*76*	0
Non-Road transport	100	0	3500	0	0	400	700	*3*	0
Waste disposal	600	600	6600	0	0	600	0	*3*	4000
Agriculture	0	0	0	0	0	0	0		0
Total	**50400**	**25600**	**647500**	**50400**	**84300**	**374500**	**251600**	**41845**	**2173000**

Annual emissions of heavy metals in Portugal per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*1235*	*1460*	*12757*	*2727*	*2899*	*3688*	*46405*	*1703*	*27934*
Residential, commercial and other	*184*	*343*	*1010*	*47*	*602*	*870*	*602*	*1*	*6951*
Industry	*1540*	*3129*	*22584*	*1640*	*7178*	*3080*	*45815*	*22841*	*34894*
Solvent and product use									
Road transport	*92*		*29*		*414*	*10237*	*517*	*54*	*22439*
Non-Road transport	*3*	*2*	*1160*	*16*	*16*	*1670*	*23*	*9*	*304*
Waste disposal	*187*	*1862*	*1921*	*84*	*1262*	*1683*	*337*	*22*	*28607*
Agriculture									
Total	**3241**	**6796**	**39461**	**4515**	**12371**	**21228**	**93698**	**24630**	**121128**

Annual emissions of heavy metals in Romania per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*4743*	*2679*	*12867*	*2740*	*3649*	*9094*	*48615*	*1020*	*45224*
Residential, commercial and other	*136*	*251*	*915*	*57*	*498*	*833*	*299*	*16*	*7155*
Industry	*12409*	*5920*	*88752*	*1742*	*7251*	*8220*	*31027*	*8611*	*619460*
Solvent and product use									
Road transport	*26*		*495024*		*132*	*4449*	*184*	*26*	*2779*
Non-Road transport	*5*	*4*	*5940*	*49*	*29*	*2952*	*1914*	*39*	*376*
Waste disposal	*47*	*304*	*864*	*13*	*199*	*266*	*53*	*3*	*4519*
Agriculture									
Total	**17368**	**9158**	**604363**	**4602**	**11758**	**25813**	**82092**	**9715**	**679514**

Annual emissions of heavy metals in Russian Federation per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*48599*	*49146*	*825778*	*65327*	*49063*	*207845*	*563352*	*32874*	*1956124*
Residential, commercial and other	*8392*	*12080*	*92263*	*9342*	*38092*	*88577*	*86653*	*5003*	*403617*
Industry	*53903*	*18621*	*955305*	*50325*	*1311079*	*333449*	*696038*	*35831*	*2389560*
Solvent and product use									
Road transport	*421*		*3939257*		*1973*	*56600*	*2595*	*318*	*77143*
Non-Road transport	*49*	*49*	*44794*	*474*	*269*	*113704*	*19704*	*426*	*3142*
Waste disposal	*150*	*226*	*4370*	*7*	*106*	*141*	*28*	*2*	*2403*
Agriculture									
Total	**111514**	**80122**	**5861768**	**125475**	**1400582**	**800316**	**1368371**	**74454**	**4831990**

Annual emissions of heavy metals in Slovak Republic per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	23	36	588	1248	1027	940	1161	212	1220
Residential, commercial and other	38	43	1000	4843	1543	1439	1314	82	2422
Industry	6478	3725	59873	5115	4539	17638	20488	6760	49440
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	13	0	1800	0	63	2133	88	13	1256
Non-Road transport	1	*0*	0	0	4	144	6	1	85
Waste disposal	694	566	11081	13	883	1391	516	7	4766
Agriculture	0	0	0	0	0	0	0	0	0
Total	**7248**	**4371**	**74343**	**11219**	**8059**	**23685**	**23572**	**7075**	**59190**

Annual emissions of heavy metals in Slovenia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	480	290	990	*471*	*289*	*1017*	*671*	*87*	*7214*
Residential, commercial and other	30	*50*	160	*39*	*114*	*182*	*292*	*6*	*1010*
Industry	410	290	7910	*278*	*892*	*428*	*3276*	*299*	*12733*
Solvent and product use									
Road transport	620		28090		*86*	*2324*	*110*	*12*	*4159*
Non-Road transport	*0*	*0*	*248*	*1*	*1*	*507*	*1*	*0*	*13*
Waste disposal	*2*	*14*	*62*	*0*	*4*	*5*	*1*	*0*	*91*
Agriculture									
Total	**1542**	**644**	**37459**	**789**	**1387**	**4463**	**4352**	**404**	**25219**

Annual emissions of heavy metals in Sweden per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	90	130	1660	180	430	910	3100	240	28880
Residential, commercial and other	127	26	770	47	78	535	692	98	3928
Industry	190	460	6900	330	5900	3100	12423	230	45000
Solvent and product use	0	0	0	0	0	0	0	0	0
Road transport	17	0	2457	0	0	10290	0	0	14350
Non-Road transport	1	0	23	37	54	280	1500	1	170
Waste disposal	0	130	1	0	0	1	0	0	0
Agriculture	0	0	0	0	0	0	0	0	0
Total	**425**	**746**	**11811**	**594**	**6462**	**15116**	**17715**	**569**	**92328**

Annual emissions of heavy metals in Turkey per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	*5834*	*3468*	*20895*	*3572*	*4286*	*12056*	*54805*	*1310*	*66278*
Residential, commercial and other	*1290*	*1856*	*7354*	*859*	*4573*	*6685*	*18525*	*424*	*39091*
Industry	*9283*	*12845*	*148783*	*10931*	*30816*	*50708*	*150132*	*18893*	*361398*
Solvent and product use									
Road transport	*156*		*581805*		*691*	*16379*	*856*	*88*	*38439*
Non-Road transport	*13*	*7*	*4159*	*99*	*70*	*4189*	*2774*	*60*	*1082*
Waste disposal	*63*	*71*	*1872*	*2*	*28*	*37*	*7*	*0*	*633*
Agriculture									
Total	**16640**	**18247**	**764867**	**15463**	**40463**	**90054**	**227099**	**20775**	**506921**

Annual emissions of heavy metals in Ukraine per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	5449	10330	241688	15196	6168	48795	36637	7708	481956
Residential, commercial and other	1847	2699	27215	2755	10187	26951	18971	1531	110307
Industry	16245	8880	580504	12295	47637	100224	91537	7942	687220
Solvent and product use									
Road transport	44		824166		195	4815	242	24	11381
Non-Road transport	14	0	27919	70	68	17246	95	14	1353
Waste disposal	83	425	1756	18	273	364	73	5	6192
Agriculture									
Total	**23682**	**22334**	**1703249**	**30334**	**64528**	**198396**	**147555**	**17224**	**1298409**

Annual emissions of heavy metals in Federal Republic of Yugoslavia per source category in 2000 (kg per year)

Sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Public heat and power	6910	4118	13923	2845	2322	13722	8140	109	68229
Residential, commercial and other	267	436	1838	204	1120	1800	3029	81	9503
Industry	1448	922	14818	2119	1292	12052	8526	2165	39785
Solvent and product use									
Road transport	18		268882		88	2986	123	18	1794
Non-Road transport						660			
Waste disposal	10	8	309	0	2	3	1	0	51
Agriculture									
Total	**8653**	**5484**	**299771**	**5168**	**4824**	**31223**	**19819**	**2372**	**119362**

Annex 5 Distribution of heavy metal emissions by species over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000, projected Cd, Hg and Pb emissions for 2010 and 2020 assuming autonomous measures, current legislation and current ratification of the HM Protocol and projected Cd, Hg and Pb emissions for 2020 assuming Full Implementation of the HM Protocol

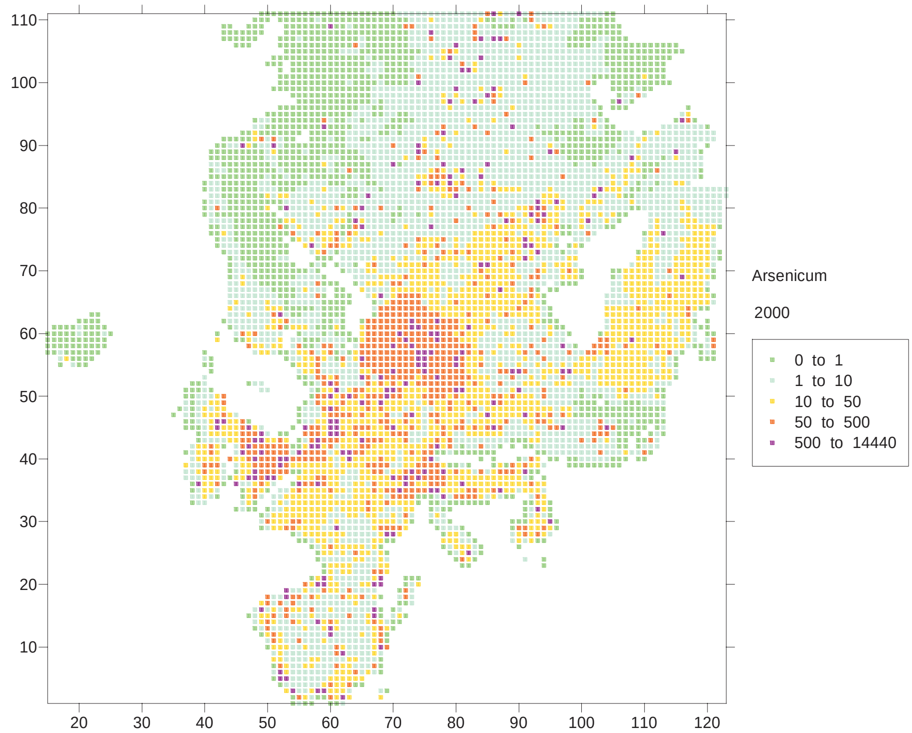

Figure A5.1. *Distribution of the emissions of arsenic over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

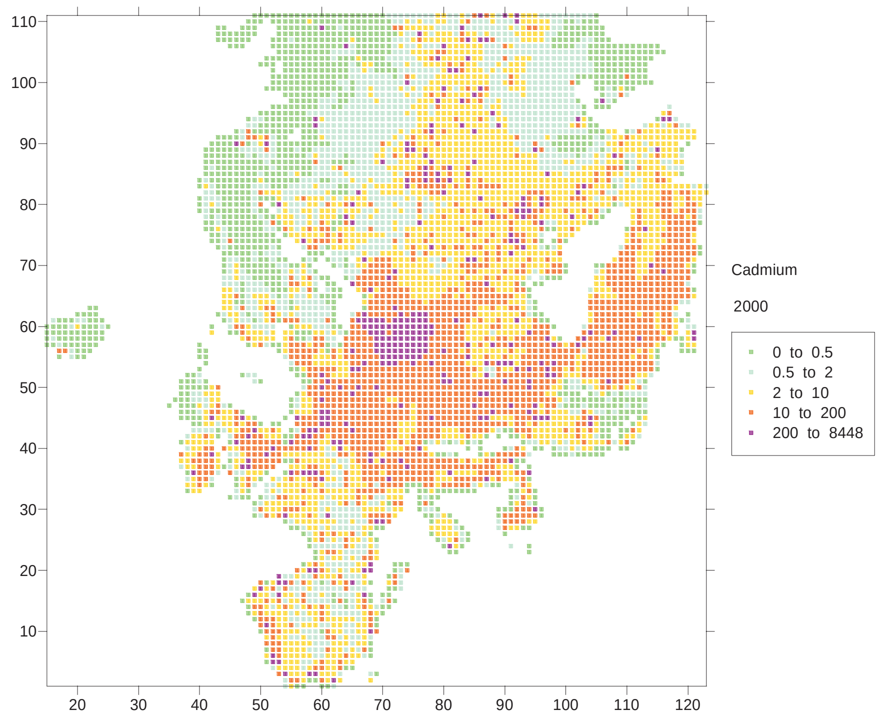

Figure A5.2. *Distribution of the emissions of cadmium over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

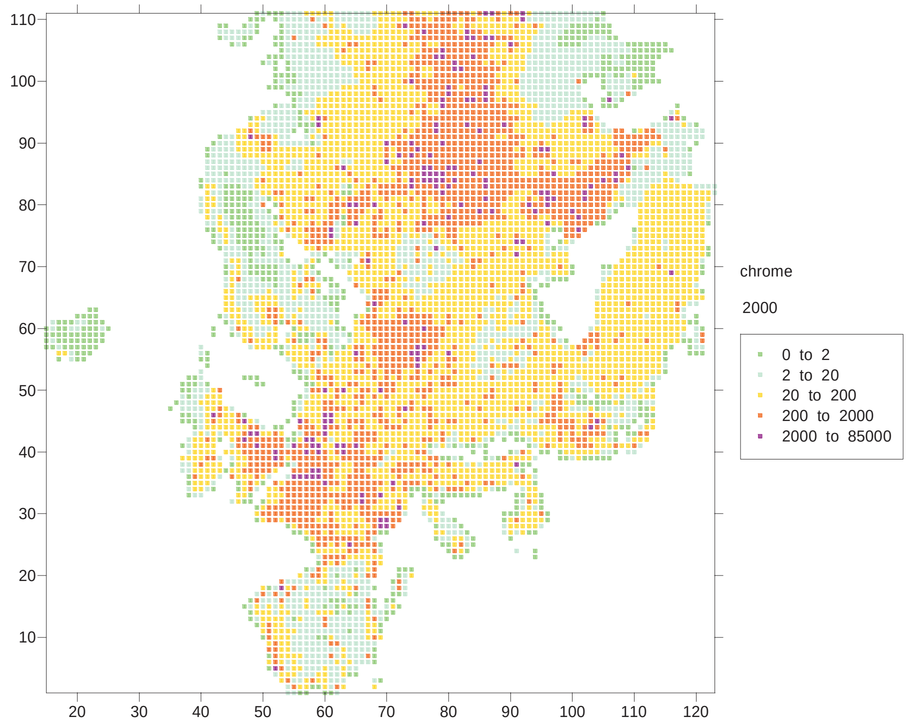

Figure A5.3. Distribution of the emissions of chromium over the 50 x 50 km² EMEP grid for UNECE-Europe in 2000 (kg/grid cell).

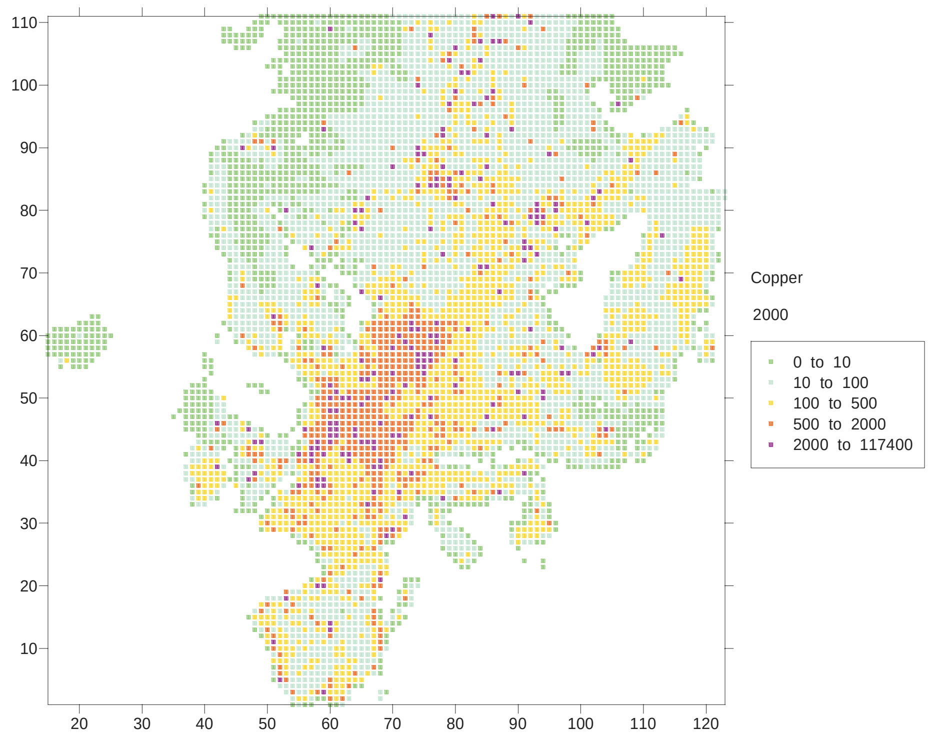

Figure A5.4. Distribution of the emissions of copper over the 50 x 50 km² EMEP grid for UNECE-Europe in 2000 (kg/grid cell).

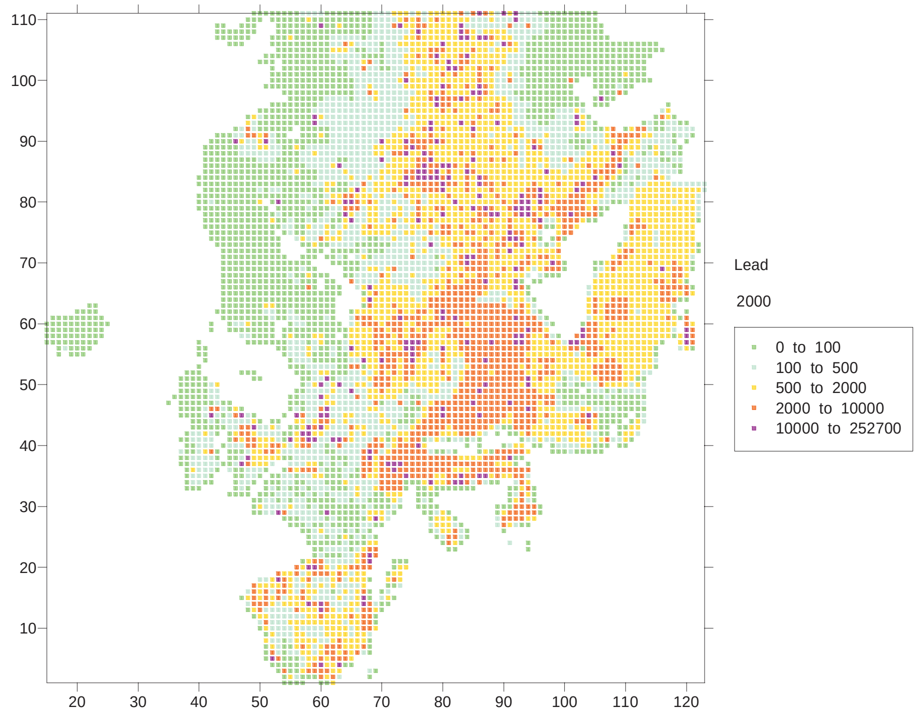

Figure A5.5. *Distribution of the emissions of lead over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

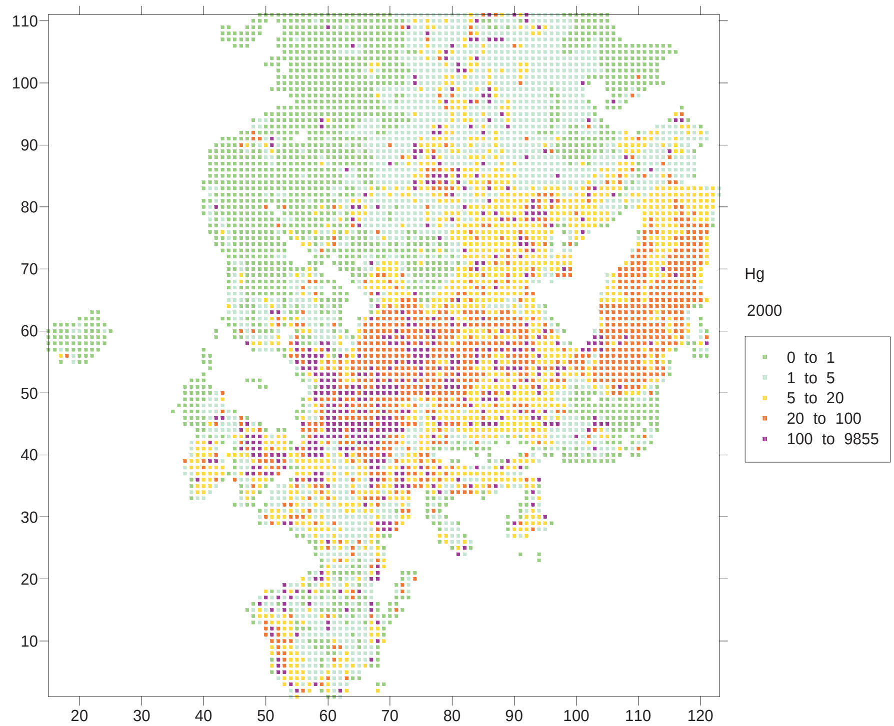

Figure A5.6. *Distribution of the emissions of mercury over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

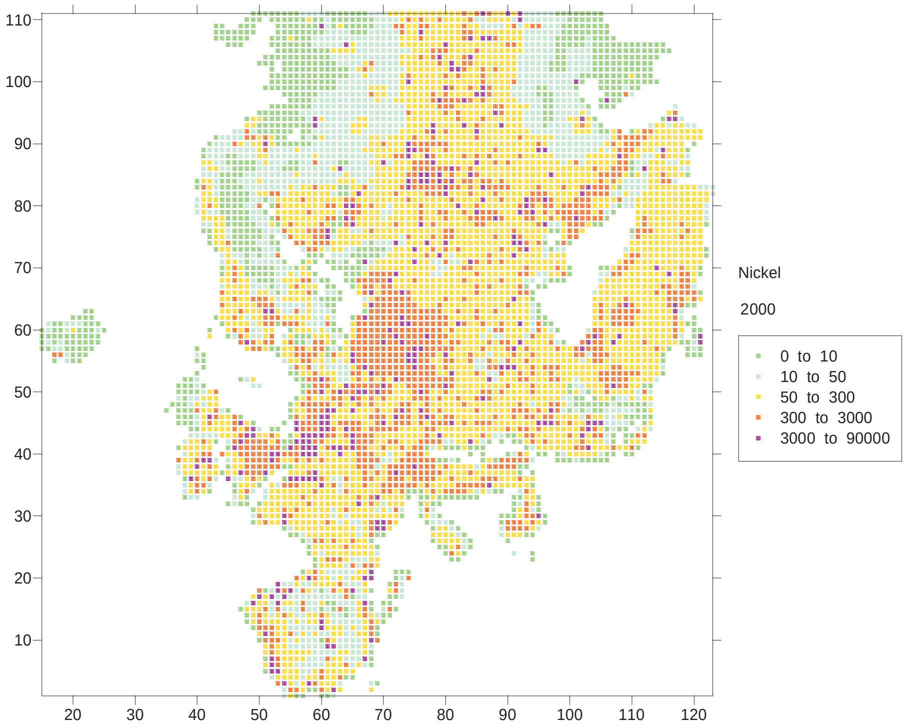

Figure A5.7. *Distribution of the emissions of nickel over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

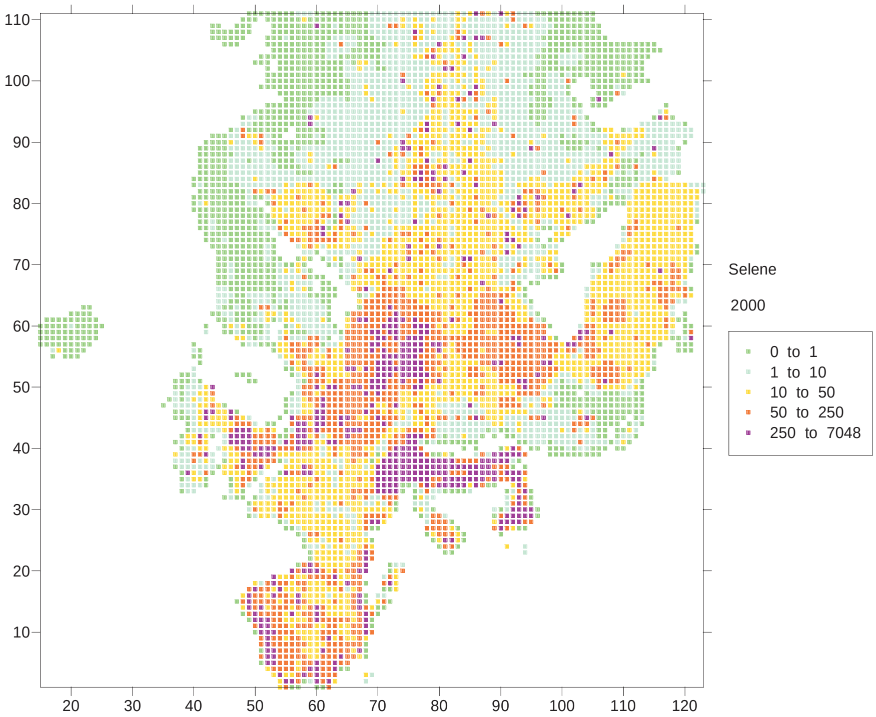

Figure A5.8. *Distribution of the emissions of selenium over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2000 (kg/grid cell).*

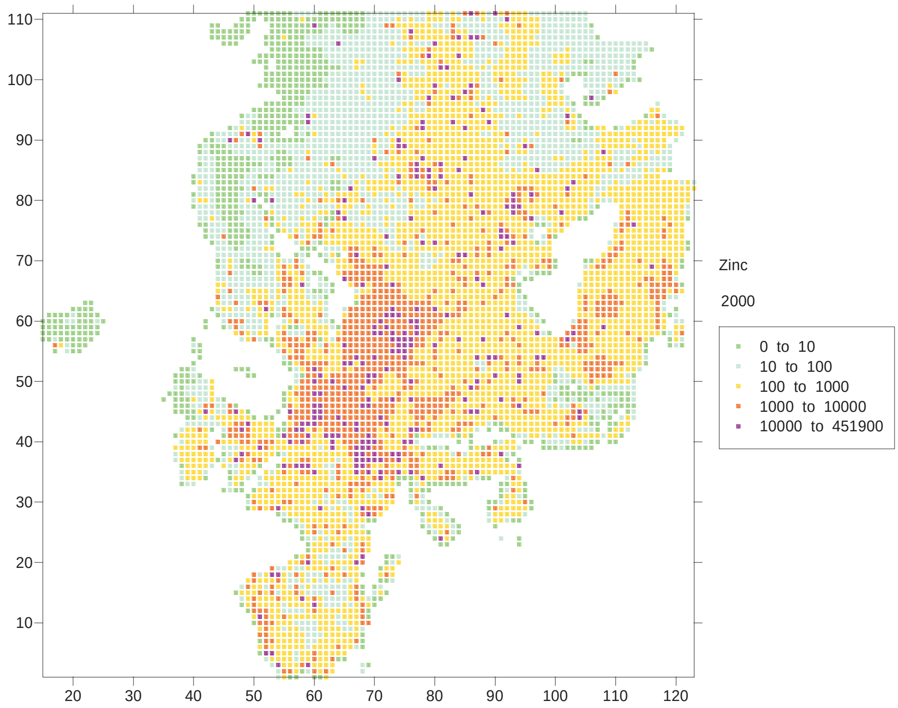

Figure A5.9. Distribution of the emissions of zinc over the 50 x 50 km² EMEP grid for UNECE-Europe in 2000 (kg/grid cell).

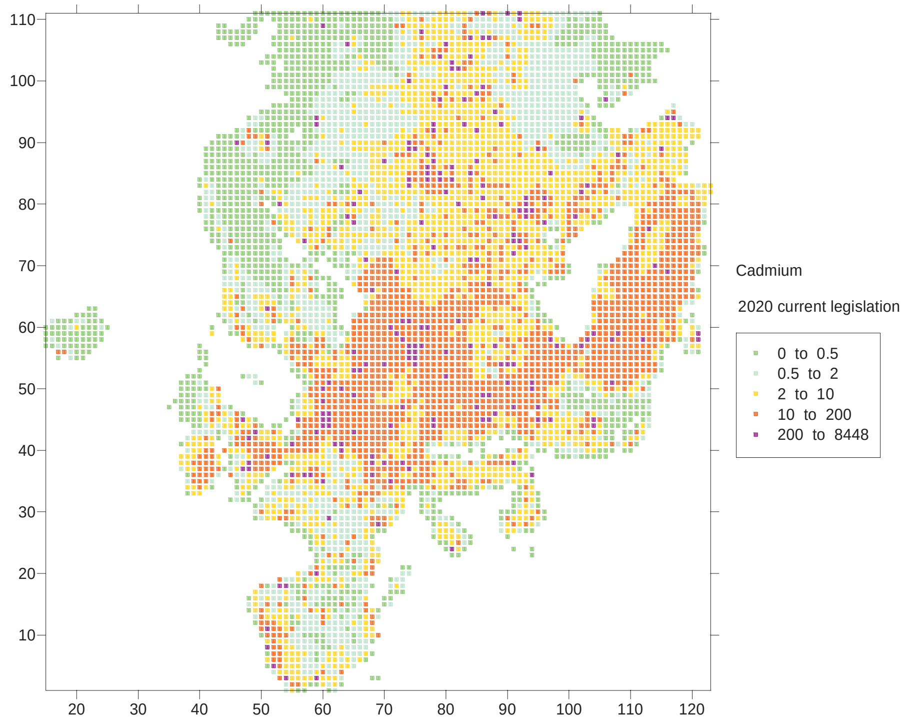

Figure A5.10. *Distribution of the projected emissions of cadmium over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and current ratification of the HM Protocol (kg/grid cell).*

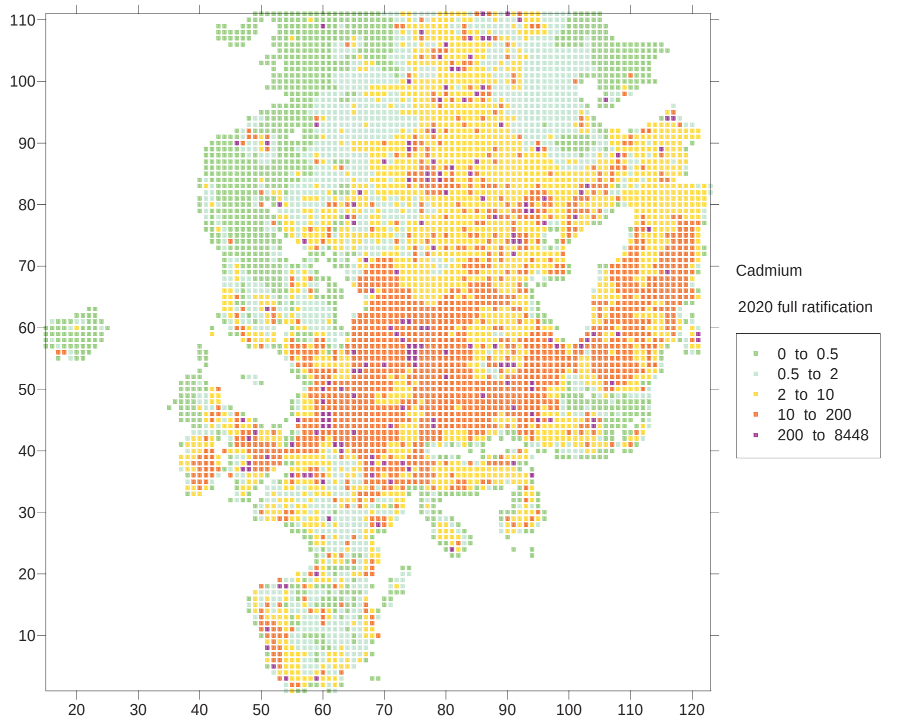

Figure A5.11. *Distribution of the projected emissions of cadmium over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and Full Implementation of the HM Protocol by all UNECE-Europe countries (kg/grid cell).*

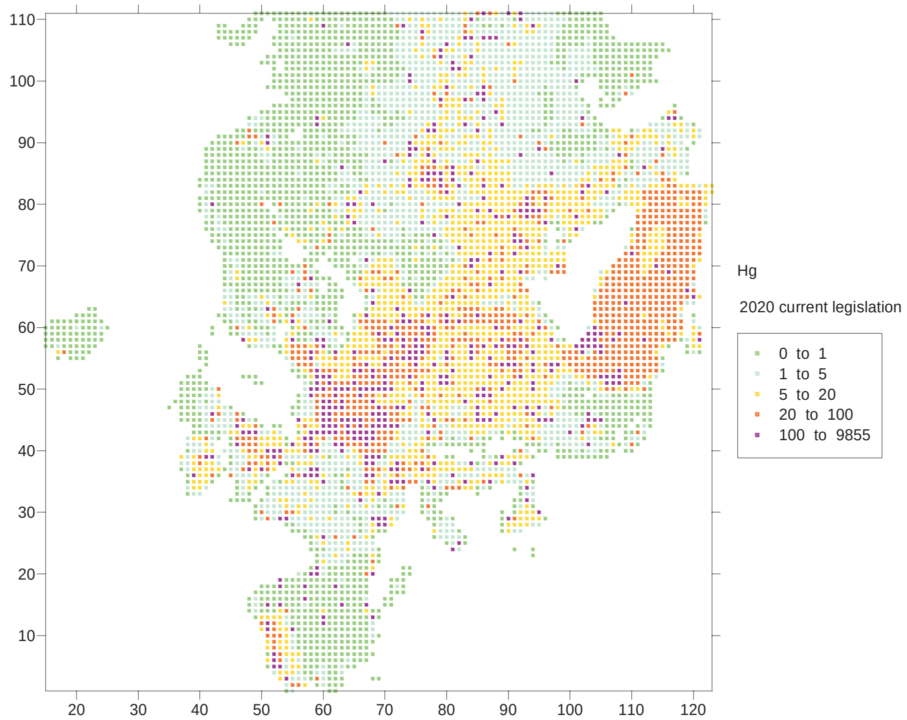

Figure A5.12. Distribution of the projected emissions of mercury over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and current ratification of the HM Protocol (kg/grid cell).

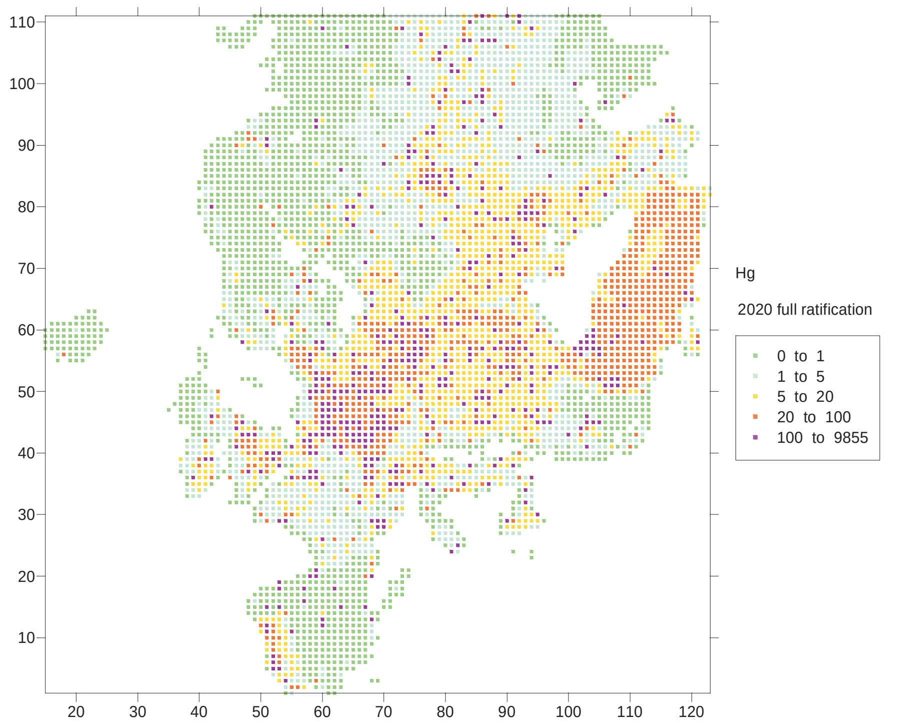

Figure A5.13. Distribution of the projected emissions of mercury over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and Full Implementation of the HM Protocol by all UNECE-Europe countries (kg/grid cell).

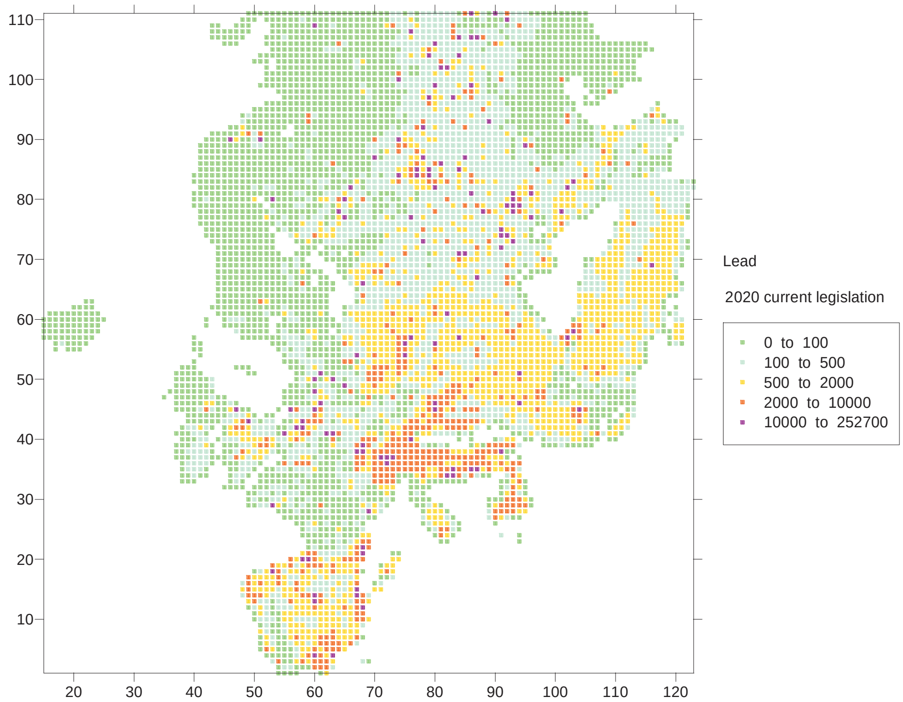

Figure A5.14. Distribution of the projected emissions of lead over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and current ratification of the HM Protocol (kg/grid cell).

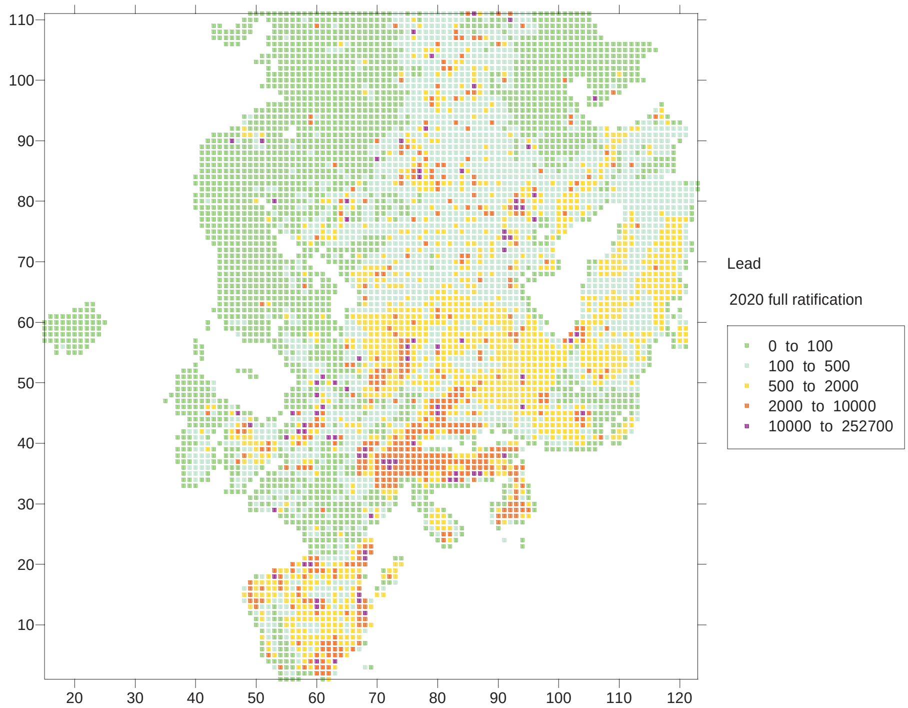

Figure A5.15. Distribution of the projected emissions of lead over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming current legislation, autonomous measures and Full Implementation of the HM Protocol by all UNECE-Europe countries (kg/grid cell).

Annex 6 Annual emissions of Heavy Metals by country per source category and fuel type in 2000 (kg per year) available on CD-ROM inserted in back cover of the report

E R R A T U M

L.S.,

Unfortunately we discovered three errors in our report "Study to the effectiveness of the UNECE Heavy Metals Protocol and costs of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the HM Protocol" (TNO report B&O-A R 2005/193), published in August 2005.

The errors involve:

- An error in the projected lead emissions from road transport:

Correction of the total projected Pb emissions.

Year_policy scenario								
2010_CLE_CRHM			2020_CLE_CRHM			2020_CLE_FIHM		
OLD	NEW	Difference	OLD	NEW	Difference	OLD	NEW	Difference
Pb tonnes/yr								
8455	**7317**	**1138**	**8835**	**7650**	**1185**	**6946**	**5761**	**1185**

See Table E1 for an overview of the corrected national emissions and the difference between old and new estimates. Because of this correction also Tables 17, 18 and 22 have been updated. See page 3, 4 and 5 of this erratum.

- A figure on Hg emissions reproduced instead of Pb emissions (Figure 6, page 57). The caption of Figure 6 is correct but the figure describes Hg emissions instead of Pb. The correct figure is added to this erratum (see page 6)

- A change of Se and Pb numbers and errors in the calculation of the relative changes (%) (Table 19, page 50). The correct table is added to this erratum (see page 7).

If you have this report we kindly ask you to insert this erratum in the report.
We sincerely apologize for the inconvenience.

Hugo Denier van der Gon
Antoon Visschedijk
Maarten van het Bolscher

Table E1 Corrected projected lead emissions in UNECE Europe for 2010 and 2020 following two policy scenarios.

ISO3	Year_policy scenario								
	2010_CLE_CRHM			2020_CLE_CRHM			2020_CLE_FIHM		
	OLD	NEW	Difference	OLD	NEW	Difference	OLD	NEW	Difference
	Pb (kg/yr)								
ALB	4660	4660	0	6494	6494	0	6083	6083	0
ARM	1127	1127	0	1267	1267	0	1142	1142	0
AUT	15098	15098	0	14816	14816	0	14816	14816	0
AZE	14902	14902	0	16915	16915	0	16654	16654	0
BEL	81404	81404	0	78203	78203	0	78203	78203	0
BGR	75903	75903	0	68043	68043	0	68043	68043	0
BIH	35853	35853	0	35449	35449	0	15576	15576	0
BLR	53201	53201	0	52805	52805	0	38806	38806	0
CHE	115398	115398	0	122507	122507	0	122507	122507	0
CYP	5767	5767	0	6251	6251	0	6251	6251	0
CZE	96614	12573	84041	103179	11169	92010	103179	11169	92010
DEU	593980	593980	0	647079	647079	0	647079	647079	0
DNK	7983	7983	0	5861	5861	0	5861	5861	0
ESP	929355	159389	769966	938460	163870	774590	938460	163870	774590
EST	16749	16749	0	14203	14203	0	14203	14203	0
FIN	36486	36486	0	38300	38300	0	38300	38300	0
FRA	177770	177770	0	179014	179014	0	179014	179014	0
GBR	101596	101596	0	100605	100605	0	100605	100605	0
GEO	8414	8414	0	10481	10481	0	10181	10181	0
GRC	133339	8905	124434	137933	8485	129449	137933	8485	129449
HRV	168640	8856	159785	197136	8684	188453	196713	8260	188453
HUN	32360	32360	0	33897	33897	0	33897	33897	0
IRL	7254	7254	0	6478	6478	0	6478	6478	0
ISL	196	196	0	173	173	0	172	172	0
ITA	839602	839602	0	812905	812905	0	812905	812905	0
KAZ	687372	687372	0	701572	701572	0	416719	416719	0
KGZ	11989	11989	0	12273	12273	0	8272	8272	0
LTU	21607	21607	0	28357	28357	0	28357	28357	0
LUX	3884	3884	0	4018	4018	0	4018	4018	0
LVA	791	791	0	1109	1109	0	1109	1109	0
MDA	3063	3063	0	3266	3266	0	3266	3266	0
MKD	44958	44958	0	45775	45775	0	28340	28340	0
NLD	39536	39536	0	38059	38059	0	38059	38059	0
NOR	6806	6806	0	7539	7539	0	7539	7539	0
POL	282931	282931	0	224645	224645	0	224645	224645	0
PRT	18357	18357	0	20501	20501	0	20501	20501	0
ROM	85353	85353	0	101278	101278	0	101278	101278	0
RUS	2480810	2480810	0	2661139	2661139	0	1558887	1558887	0
SVK	28890	28890	0	27542	27542	0	27542	27542	0
SVN	13141	13141	0	12866	12866	0	12866	12866	0
SWE	11468	11468	0	13713	13713	0	13713	13713	0
TUR	283553	283553	0	382711	382711	0	314476	314476	0
UKR	825205	825205	0	861659	861659	0	500061	500061	0
YUG	51478	51478	0	58326	58326	0	42894	42894	0
Grand Total	8454841	7316615	1138226	8834803	7650302	1184502	6945602	5761100	1184502

Table 17 Annual emissions of heavy metals in UNECE-Europe per source category in 2000, 2010, 2015 and 2020 (tones per year). Projections for 2010-2020 are made following the IIASA CLE-BL scenario and assuming current (as of April 2005) ratification of HM Protocol and including foreseen autonomous measurements (BL_CLE_CRHM).

Source secto	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
						Tonnes/yr				
1_PHP	2000	176	99	177	454	133	1491	1547	108	3943
	2010	153	99	130	421	135	1371	1623	85	3892
	2015	148	96	124	411	132	1285	1585	81	3872
	2020	145	91	112	402	134	1123	1557	80	3992
2_RCO	2000	57	49	121	278	29	410	390	17	1458
	2010	43	41	108	236	29	330	320	13	1274
	2015	38	37	99	209	27	287	284	11	1142
	2020	34	34	90	186	25	252	252	10	1008
3_IND	2000	318	214	2005	1287	142	2130	4466	371	12355
	2010	250	173	2040	1027	146	1930	3499	213	10776
	2015	255	179	2214	1071	149	1953	3554	223	11127
	2020	255	184	2388	1127	150	1922	3693	229	11598
4_SPU	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
5_ROT	2000	0	6	19	460	0	34	8329	3	1051
	2010	0	8	25	566	0	46	1650	4	1432
	2015	0	8	28	611	0	52	1779	4	1577
	2020	0	9	31	661	0	57	1946	4	1757
6_NRT	2000	1	1	2	327	0	62	154	2	23
	2010	2	1	2	359	0	63	135	2	22
	2015	1	1	1	363	0	63	117	2	21
	2020	1	1	1	363	0	64	112	2	21
7_WAS	2000	2	9	27	40	39	15	134	1	674
	2010	2	5	23	33	17	8	90	1	629
	2015	2	5	23	33	17	8	90	1	630
	2020	2	5	23	33	17	8	91	1	631
8_AGR	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
Total	2000	555	377	2350	2846	344	4144	15021	501	19503
	2010	449	327	2328	2642	328	3750	7317	317	18025
	2015	444	326	2489	2698	325	3649	7410	321	18369
	2020	438	323	2645	2772	326	3426	7650	325	19006

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Table 18 Projected annual emissions of heavy metals in UNECE-Europe per source category in 2000, 2010, 2015 and 2020 (tonnes per year). Projections for 2010-2020 are made following the IIASA CLE-BL scenario and assuming all UNECE countries ratify the HM Protocol before 2010 (BL_CLE_FIHM).

Source secto	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
						Tonnes/yr				
1_PHP	2000	176	99	177	454	133	1491	1547	108	3943
	2010	73	45	93	120	129	1302	442	56	1155
	2015	70	43	87	116	125	1217	428	53	1187
	2020	69	39	76	113	127	1057	427	53	1366
2_RCO	2000	57	49	121	278	29	410	390	17	1458
	2010	43	41	108	236	29	330	320	13	1274
	2015	38	37	99	209	27	287	284	11	1142
	2020	34	34	90	186	25	252	252	10	1008
3_IND	2000	318	214	2005	1287	142	2130	4466	371	12355
	2010	212	126	634	719	144	1313	2800	210	8468
	2015	214	129	656	738	146	1276	2831	220	8669
	2020	211	129	679	771	146	1184	2943	225	8992
4_SPU	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
5_ROT	2000	0	6	19	460	0	34	8329	3	1051
	2010	0	8	25	566	0	46	1650	4	1432
	2015	0	8	28	611	0	52	1779	4	1577
	2020	0	9	31	661	0	57	1946	4	1757
6_NRT	2000	1	1	2	327	0	62	154	2	23
	2010	2	1	2	359	0	63	135	2	22
	2015	1	1	1	363	0	63	117	2	21
	2020	1	1	1	363	0	64	112	2	21
7_WAS	2000	2	9	27	40	39	15	134	1	674
	2010	2	5	23	32	16	8	81	1	622
	2015	2	5	23	32	16	8	81	1	622
	2020	2	5	23	32	16	8	81	1	622
8_AGR	2000	0	0	0	0	0	0	0	0	0
	2010	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
Total	2000	555	377	2350	2846	344	4144	15021	501	19503
	2010	332	226	884	2033	318	3063	5428	285	12973
	2015	325	222	894	2070	315	2903	5521	290	13218
	2020	318	217	900	2126	316	2622	5761	294	13766

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Table 22 HM emission by country group in 2000, projected HM emissions for 2010, 2015 and 2020 following policy scenario BL_CLE_CRHM and projected HM emissions following policy scenario BL_CLE_FIHM.

Country group 1)	year	scenario	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
							tonnes/yr				
HM_Protocol ratified	2000		113	85	463	735	109	985	2240	109	5669
HM_Protocol ratified	2010		81	59	299	739	85	720	1288	69	5103
HM_Protocol ratified	2015		78	58	296	754	83	641	1301	68	5301
HM_Protocol ratified	2020		81	58	298	778	88	604	1365	70	5701
HM_Protocol ratified	2010	BL_CLE_FIHM	81	59	299	739	85	720	1288	69	5103
HM_Protocol ratified	2015	BL_CLE_FIHM	78	58	296	754	83	641	1301	68	5301
HM_Protocol ratified	2020	BL_CLE_FIHM	81	58	298	778	88	604	1365	70	5701
EU25 a/o 2nd S protocol	2000		212	96	326	733	85	1068	3183	257	5305
EU25 a/o 2nd S protocol	2010		108	59	195	402	73	681	1525	100	3242
EU25 a/o 2nd S protocol	2015		100	55	192	386	71	622	1446	104	3183
EU25 a/o 2nd S protocol	2020		88	47	177	373	67	411	1439	106	3198
EU25 a/o 2nd S protocol	2010	BL_CLE_FIHM	108	59	151	402	73	659	1525	100	3240
EU25 a/o 2nd S protocol	2015	BL_CLE_FIHM	100	55	145	385	71	598	1446	104	3182
EU25 a/o 2nd S protocol	2020	BL_CLE_FIHM	88	47	128	373	67	387	1438	106	3197
Other 2)	2000		230	196	1560	1377	150	2091	9597	135	8529
Other 2)	2010		260	208	1833	1501	170	2349	4504	148	9679
Other 2)	2015		265	214	2001	1559	171	2386	4663	149	9885
Other 2)	2020		269	218	2169	1621	172	2411	4847	149	10107
Other 2)	2010	BL_CLE_FIHM	143	107	434	891	160	1684	2616	116	4629
Other 2)	2015	BL_CLE_FIHM	146	110	454	931	161	1663	2774	118	4736
Other 2)	2020	BL_CLE_FIHM	149	112	474	975	162	1631	2958	118	4868
Total UNECE	2000		555	377	2350	2846	344	4144	15021	501	19503
Total UNECE	2010		449	327	2328	2642	328	3750	7317	317	18025
Total UNECE	2015		444	326	2489	2698	325	3649	7410	321	18369
Total UNECE	2020		438	323	2645	2772	326	3426	7650	325	19006
Total UNECE	2010	BL_CLE_FIHM	332	226	884	2033	318	3063	5428	285	12973
Total UNECE	2015	BL_CLE_FIHM	325	222	894	2070	315	2903	5521	290	13218
Total UNECE	2020	BL_CLE_FIHM	318	217	900	2126	316	2622	5761	294	13766

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ERRATUM

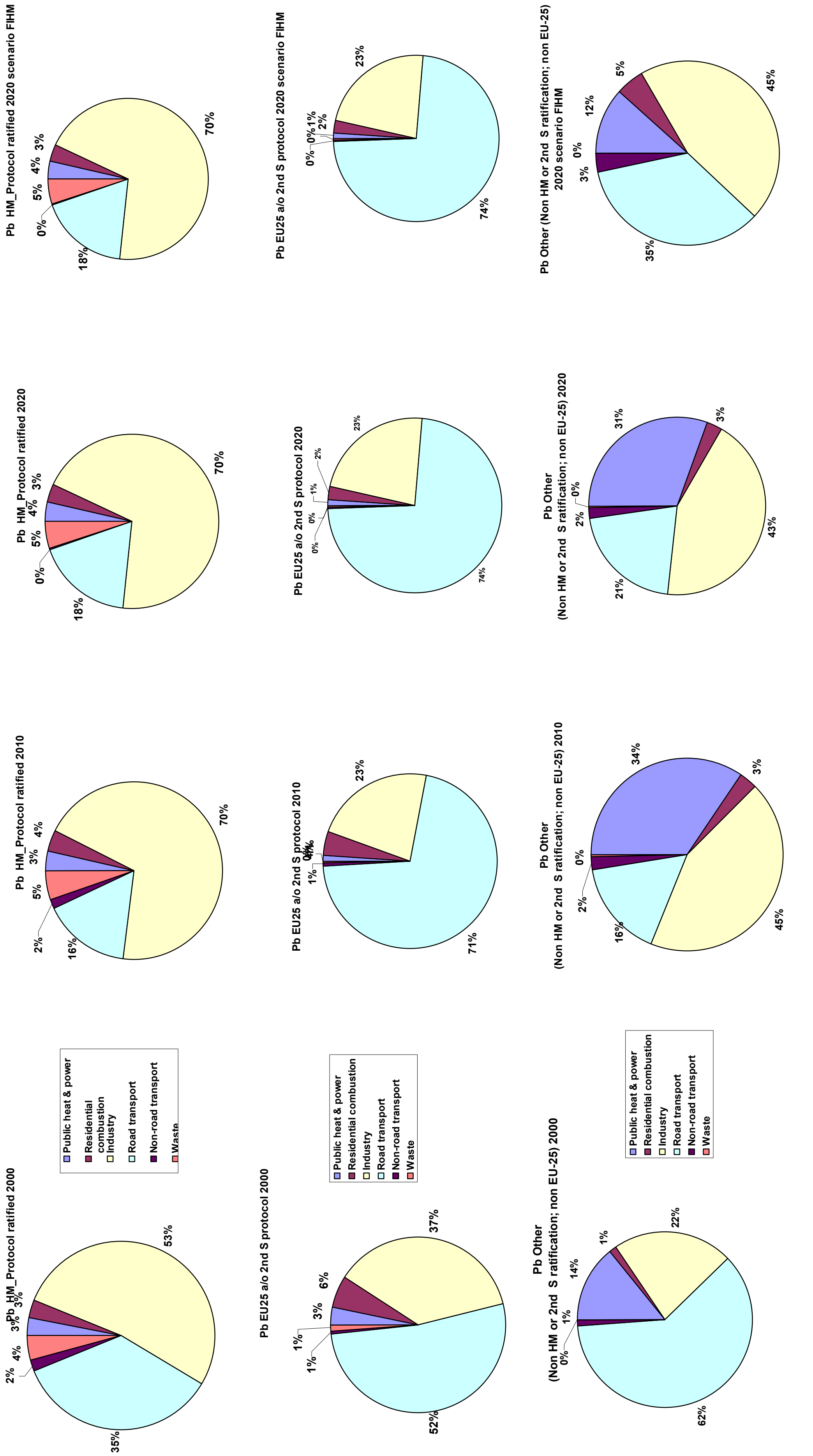

Figure 6 Relative source sector contributions to lead emissions for three different country groups in 2000, 2010, 2020 with current ratification and autonomous measures and 2020 assuming Full Implementation of the HM Protocol in the UNECE.

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Table 19 Projected HM emissions in the UNECE-Europe for 2010-2015-2020 following policy scenario BL_CLE_CRHM and relative change due to choice of an alternative energy pathway.

Energy pathway	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
		(tonnes/yr)								
	2000	555	377	2.350	2.846	344	4.144	15.021	501	19.503
BL	2010_CLE_CRHM	449	327	2.328	2.642	328	3.750	8.455	317	18.025
	2015_CLE_CRHM	444	326	2.489	2.698	325	3.649	8.578	321	18.369
	2020_CLE_CRHM	438	323	2.645	2.772	326	3.426	8.835	325	19.006
	Additional relative change in HM emission due to expected climate change abatement (%)									
CP	2010_CLE_CRHM	-3	-1	-1	-2	-4	-3	-1	**7**	-2
	2015_CLE_CRHM	-4	-2	-1	-2	-5	-4	-2	**7**	-2
	2020_CLE_CRHM	-3	-1	-1	-2	-7	0	-1	**7**	-3

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