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TNO-report

2006-A-R0087/B

Study to the effectiveness of the UNECE Heavy Metals (HM) Protocol and cost of additional measures

Phase II: Estimated emission reduction and cost of options for a possible revision of the HM Protocol

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Order no.	35096
Keywords	Heavy metals, emission inventory, Europe, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn
Intended for	Netherlands Ministry of Housing, Spatial Planning and the Environment

Preface

The 1998 Heavy Metals (HM) Protocol under the UNECE Convention on Long-range Transboundary Air Pollution entered into force 29 December of 2003 implying the start of the review of the Protocol. The review focuses on the sufficiency and effectiveness of the Protocol. The Executive Body asked the Task Force on Heavy Metals to finalise its 'Sufficiency and Effectiveness Review' in 2006 in time for the Executive Body meeting in 2006.

One important aspect of the review of the Protocol is to look at the development of HM emission and emission projection data. Reliable information on emissions is an important basis of work under the Convention on Long-range Transboundary Air Pollution. To support this important aspect of the review the Netherlands initiated a project entitled 'Study to the effectiveness of the UNECE Heavy Metal and POP Protocols and costs of possible additional measures' to review current data and to complete the information on emissions and emission projections when appropriate. The first phase of this project on emission inventories and projections for Heavy Metals and POPs for 2000, 2010, 2015 and 2020, was reported in 2005.

This report presents results of the second phase of the project addressing further emission reductions and incremental costs of possible additional measures, after complete implementation of the current HM Protocol. This report together with the report of the first phase provide emission scenarios that can be used to calculate exceedances of critical loads for HM to assess risks for human health and environmental receptors. A combined report with calculated exceedances of Cadmium, Lead and Mercury and 6 other HM from 1990 to 2020 is currently being prepared in collaboration with WGE, ICP M&M, Alterra (preliminary critical loads for 6 other HM), CCE, MSC-E and TNO and will be published shortly after this report.

The second phase of the TNO project already anticipates on a possible revision of the HM Protocol. This report shows that substantial further emission reductions are possible. If the Executive Body in December 2006 accepts the Sufficiency and Effectiveness Review made by the Task Force on HM it will hopefully also decide to ask the Working Group on Strategies and Review to start the revision of the Protocol.

It is my pleasure to draw your attention to this report, which I expect will bring valuable information to the review of the HM Protocol and its possible revision.

Hans Bolscher
Director Climate Change and Industry

Summary and Conclusions

The 1998 UNECE Protocol for Heavy Metals (HM) entered into force on December 30, 2003. In the review of the Protocol an assessment of the emission reduction and implementation costs of a possibly revised Protocol will be needed. The Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has commissioned TNO to do a study on the effectiveness of the UNECE Heavy Metals (HM) Protocol and cost of additional measures, consisting of two phases. Phase I has been reported in 2005 (Denier van der Gon et al., 2005) and comprised an update of the previous 1990 emission inventory, including actualisation of emission data to the year 2000 and new projections for 2010-2015-2020, geographical allocation of these emissions, efficiency of the current Protocols and an inventory of additional reduction measures. Phase II is reported here and comprises an estimation of the emission reduction as well as costs of options for a revision of the HM Protocol. The rationale behind Phase II is that during the review of the HM Protocol there will be a need for an assessment of the potential for further emission reduction and costs of a possible revision of the Protocol.

Source sectors considered for a possible revision of the HM Protocol have been selected based on a key source analysis on the remaining emissions upon full implementation of the 1998 HM Protocol and the following criteria:

1. The contribution to the total emission of one or more of the three priority metals (Cd, Hg and Pb) exceeds 5%
2. The contribution to the total emission of one or more of the other heavy metals exceeds 15%
3. Emissions from domestic / residential sources are not considered for revision of the HM Protocol in this study
4. Sources that are scheduled for re-evaluation by the Task Force (TF) on HM will be included (HM emissions from Chlor-alkali industry and Medical Waste Incineration)

The total selected sources (Table S1) cover 74-86% of the priority HM emissions and 64-94% of the other HM. This indicates the potential for reduction, not the actual reduction that will be achieved. For all HM the contribution of residential sources is ~10% (3-15%) but residential combustion is not considered for revision of the HM Protocol because of foreseen difficulties in implementation, legislation and enforcement. To reduce the risk that the analysis performed in the current study would not include the relevant Pb sources if the Pb emission of road transport would prove to be overestimated, iron and steel oxygen furnaces with a contribution just below 5% of the total Pb emissions has been included in the selection of sources under consideration for revision of the Protocol (Table S1).

Tabel S1 Selected source categories for possible further HM emission reduction.

Source categories to be addressed based on key source criteria	
Heat / Power Plants	Primary Copper Production
Heat / Power Plants	Primary Zinc Production
Industrial Combustion	Primary Nickel Production
Industrial Combustion	Primary Lead Production
Iron & Steel, Blast furnaces	Chlorine Production
Iron & Steel, Sinter Production	Cement Production
Iron & Steel, Electric Arc Furnace	Glass Production
Coke Ovens	Road Transport (Exhaust)
Iron & Steel, Oxygen Furnace[a)]	Medical Waste Incineration

a) covering 4.4% of total Pb emission, added because of uncertainty concerning Pb emission source strength from traffic.

The potential measures and their associated costs for HM emission reduction of the selected sources are discussed by source type. The possible measures are basically derived from the following references: The IFARE review of the BAT and ELVs for all source categories listed in Annex II to the Protocol (Rentz et al., 2004a), earlier submitted to the TF HM, the preliminary listing of measures in Phase I of the present study (Denier van der Gon et al., 2005), BAT conclusions of the respective European Reference Documents on Best Available Techniques (BREF), Entec (2001) regarding costs of meeting future ELVs and earlier work by TNO (Berdowski et al., 1998). For most sources the proposed measures bring about a modification to an existing installation in order to meet the proposed emission limit value. In such cases a non-recurring investment has to be made. In this study both investment costs and operational costs have been estimated and expressed as annual costs. Based on the technical life expectancy of the emission control units, an amortisation period of 20 years is chosen. The calculations are based on an interest rate of 4% This results in an annuity of 7.4%, in line with the assumptions in the IIASA RAINS model (Amann et al., 2005).

The measures considered for a possible revision of the HM Protocol in this study are separated in a Package 1 and Package 2 proposal. Package 1 focuses on (further) dust removal, the more traditional way to reduce emissions of HM. Mercury is often poorly mitigated by such general HM reduction measures which focus on dust removal and dust emission limit values. Therefore, the Package 2 proposal specifically addresses Hg emissions that are poorly mitigated by the tightening of the dust ELVs outlined in Package 1. In general Package 2 measures are more expensive. However, in some cases (e.g. a proposed fuel switch from fuel oil to gas) a Package 2 measure will make the Package 1 measure for a particular source redundant.

Emission reduction due to possible additional measures

The cost and emission reduction of a set of emission control measures including revised emission limit values (ELVs) for heavy metals and particulate matter, have been estimated by source category. The results for each individual country are presented in Annex 2 of this report (available on CD-ROM inserted in the back of this report). Since we assume full implementation of the HM Protocol by all countries in 2020, the major discrepancy between countries is the foreseen (mandatory) autonomous developments. Therefore, the split between countries is limited to two country groups, EU(25), Norway and Switzerland (EU(25)+) and non-EU(25)+. The rationale of the country split is the difference in associated costs and additional emission reduction achieved due to differences in autonomous policies implemented in both country groups. As a result the costs for the two Packages of revision defined in the present study are quite different because the starting point in the present study is that costs made by autonomous policies are not accounted for. However, one should realize that the costs to abate HM emissions will be made in all countries; in the EU(25)+ countries these costs will be attributed to EU Directives instead of a possibly revised HM Protocol.

The remaining emission (in tonnes) after implementation of Package 1 measures for the three priority heavy metals (Cd, Hg and Pb) and 6 others (As, Cr, Cu, Ni, Se and Zn) is presented in Table S2. The costs and achieved emission reduction of a possible revised HM Protocol has been estimated for each individual European UNECE Member State (Annex 2, on CD-ROM).

The second set of measures evaluated in the study is referred to as " Package 2". Package 2 focuses specifically on the control of Hg emission. The results (summarized in Table S2) show that with Package 2 measures the Hg emission reduction due to revision of the HM Protocol is much higher than for Package 1 measures (131 and 9 tonnes, respectively). However, costs of Package 2 measures are approximately twice the costs of the Package 1 measures. This is mostly caused by implementation of expensive Hg abatement measures in the EU(25)+ countries.

Table S2 Emission of heavy metals in UNECE Europe in 2020 before and after revision of the HM Protocol following two separate revision Packages and achieved emission reductions and costs for Package 1, Package 2 and Package 1+2 .

Country group	**Emission in 2020 after full implementation of 1998 HM Protocol[a)] (tonnes)**									**Costs (M€)**
	Cd	**Hg**	**Pb**	**As**	**Cr**	**Cu**	**Ni**	**Se**	**Zn**	
EU(25)+	95	141	2622	165	415	1107	904	155	8615	
non-EU(25)+	121	175	3139	153	485	1019	1717	140	5150	
UNECE Europe	217	316	5761	318	900	2126	2622	294	13766	
	Emission after Protocol Revision (tonnes) - Package 1									
EU(25)+	81	141	1548	148	276	1026	613	149	8000	
non-EU(25)+	68	166	1265	79	166	704	814	70	3061	
UNECE Europe	149	307	2812	227	442	1729	1427	220	11061	
	Emission Reduction due to Revision (tonnes) - Package 1									*Package 1*
EU(25)+	14	0.4	1074	17	139	81	291	5	615	1344
non-EU(25)+	53	9	1874	74	319	315	903	69	2089	7637
UNECE Europe	68	9	2949	91	458	396	1194	75	2704	8981
	Emission after Protocol Revision (tonnes) - Package 2									
EU(25)+	87	90	2605	148	369	1095	524	146	8610	
non-EU(25)+	99	95	3100	130	431	998	628	119	5146	
UNECE Europe	186	185	5705	278	800	2093	1152	266	13756	
	Emission Reduction due to Revision (tonnes) - Package 2									*Package 2*
EU(25)+	9	51	17	17	46	12	380	9	5	10633
non-EU(25)+	22	80	39	23	54	21	1089	20	4	7928
UNECE Europe	31	131	56	40	100	33	1469	29	9	18560
	Emission after Protocol Revision (tonnes) - Package 1+2									
EU(25)+	77	90	1540	141	265	1021	467	145	7998	
non-EU(25)+	60	95	1250	71	156	698	497	61	3060	
UNECE Europe	137	185	2790	211	421	1719	964	206	11057	
	Emission Reduction due to Revision (tonnes) - Package 1+2									*Package 1+2*
EU(25)+	18	52	1082	24	151	86	438	10	617	11936
non-EU(25)+	62	81	1889	82	329	321	1220	79	2090	15454
UNECE Europe	80	132	2971	107	480	407	1657	89	2708	27391

a) Projected annual emissions of heavy metals in 2020 following IIASA CLE-BL scenario and assuming all UNECE countries ratify the HM Protocol before 2010 (Denier van der Gon et al., 2005).

The emission reduction achieved by full implementation of the measures proposed by Package 1, package 2 or both combined relative to the 2020 HM emissions after full implementation of the 1998 HM Protocol is presented in Table S3. This Table gives a quick insight in the effectiveness of proposed measures. Revision of the HM Protocol following the Package 1 measures effectively addresses the Cd and Pb emission in UNECE-Europe as well as Cr and Ni emissions (Table S2, S3, Figure S1). The reduction achieved in the EU(25)+ is (for every individual HM) lower than the emission reduction achieved in the non-EU(25)+ countries. This is because it is assumed that the implementation of the EU IPPC Directive (and other EU Directives) is autonomous policy for the EU(25)+ countries. It can be seen that the effectiveness for Cu, As, Se and Zn lags behind (Table S3). Road transport is an important source of Cu and Zn emissions (brake wear and tire wear, respectively) and not specifically addressed in the revised Protocol.

Table S3 Relative emission reduction due implementation of possible additional measures (Package 1, Package 2, Package 1+2) compared to HM emissions in 2020 upon full implementation of the 1998 HM Protocol.

Region	Cd	Hg	Pb	As	Cr (%)	Cu	Ni	Se	Zn
Relative Emission Reduction due to Revision - Package 1									
EU(25)+	15	0	41	10	33	7	32	3	7
non-EU(25)+	44	5	60	48	66	31	53	49	41
UNECE Europe	31	3	51	29	51	19	46	26	20
Relative Emission Reduction due to Revision - Package 2									
EU(25)+	9	36	1	10	11	1	42	6	0
non-EU(25)+	18	46	1	15	11	2	63	14	0
UNECE Europe	14	41	1	13	11	2	56	10	0
Relative Emission Reduction due to Revision - Package 1+2									
EU(25)+	19	37	41	15	36	8	48	6	7
non-EU(25)+	51	46	60	54	68	32	71	56	41
UNECE Europe	37	42	52	34	53	19	63	30	20

Mercury emissions are only marginally abated by Package 1 measures (Figure S1) The relative decrease of Hg emissions as a result of tightening the Protocol ELVs following Package 2 measures is high for both country groups and boosts the reduction potential to ~ 40% of the original 2020 emission. Please note that the emission reduction due to implementation of Package 1 and Package 2 is not the sum of the individual Package 1 and 2 emission reductions as listed in Table S2 because some double counting occurs – if a fuel switch is proposed for a certain sector in Package 2 than the reduction technique proposed in Package 1 for this sector will not be implemented.

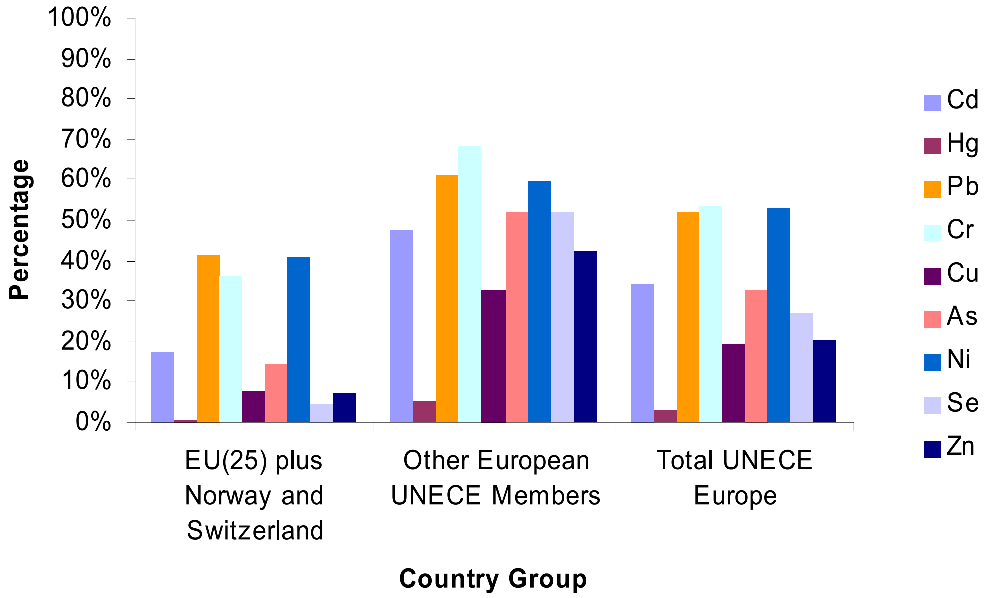

Figure S1 Emission reduction potential of a possible revision of the HM Protocol following Package 1.

The projected emissions of selected heavy metals in 2020 by source sector after a possible revision of the HM Protocol and assuming full implementation of the 1998 HM Protocol by all UNECE-Europe countries illustrate that industry will remain the largest source of HM emissions but residential combustion is becoming an important contributor as well (Table S4). Public heat and power production is no longer a dominating emitter, high contributions of road transport are predicted for Cu and Zn due to brake and tire wear, respectively.

Table S4 Projected emissions of selected heavy metals in 2020 by source sectors upon full implementation of the 1998 HM Protocol by all UNECE-Europe countries and implementation of possible additional measures (Package 1 +2).

Source sector	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
	Tonnes/yr								
Public heat and power; Excludes refineries	10	25	204	35	18	49	39	26	943
Residential, commercial and other combustion; Includes combustion in agriculture	34	25	252	34	90	186	252	10	1008
Industry; Includes both combustion and process emission, and refineries and fossil fuel production	79	117	2036	139	257	428	544	163	6707
Solvent and product use; New and existing stocks	0	0	0	0	0	0	0	0	0
Road transport	9	0	105	0	31	661	57	4	1757
Non-Road transport	1	0	112	1	1	363	64	2	21
Waste disposal	5	16	81	2	23	32	8	1	622
Agriculture; Excludes combustion emission in agriculture	0	0	0	0	0	0	0	0	0
Total of all sectors	137	185	2790	211	421	1719	964	206	11057

Costs of further HM emission reduction

The total costs in UNECE-Europe for Package 1 measures is ~9 billion € but 85% of these costs will have to be made in the non-EU(25)+ countries (Table S2, detailed breakdown in Table S5). Again, as pointed out earlier this is largely due to our starting point that costs made to meet autonomous policies (e.g. EU Directives) are not accounted for. By contrast the total costs in UNECE-Europe for Package 2 measures is ~18.5 billion € and ~60% of these costs will have to be made in the EU(25)+ countries (Table S2 and detailed breakdown in Table S6). Additional Hg emission reduction achieved by Package 2 is not covered by autonomous policies in UNECE-Europe and a revised HM Protocol could be the major motivation and incentive to actively reduce Hg emissions. The possible revision of the HM Protocol will also reduce PM emissions in UNECE-Europe but will not cause major PM emission reductions because some important PM emitting source categories (road transport, agriculture) are not addressed by a possibly revised HM Protocol. Moreover, full implementation of the 1998 HM Protocol in all UNECE-Europe countries, which is the starting point of the possible revision proposed in this study, already results in important reductions of PM emissions from HM emitting sources as a co-benefit (~ 3.7 Mtonnes TSP, 1.2 Mtonnes PM_{10} and 0.28 Mtonnes $PM_{2.5}$ (Denier van der Gon et al., 2005))

The addition of electrostatic precipitators (ESP) to residual oil-fired large combustion plants appears to be the most cost-efficient way to further reduce Cd emissions. Other relatively cost-effective measures to further reduce Cd emissions can be found in the non-ferrous metals sector and the glass industry (Table S5). For Pb, a further lowering of the Pb content of unleaded gasoline for countries where this is not yet mandatory (non-EU(25)+) seems an attractive measure which is regarded as cost-neutral and has a large reduction potential. However, the real-world effectiveness is difficult to estimate as country specific exact Pb contents of unleaded gasoline are presently not available. Other cost effective measures for Pb could be taken in the primary Pb production sector, glass production industry and for blast furnaces in the iron and steel industry (Table S5).

Table S5 Selected measures, fuel used, emission limit values Package 1, costs, cost effectiveness for Cd and Pb.

Source Category	**Fuel**	**Applied measure Stage I**	**Cost (M€/year)**	**Cost effectiveness (€/g)**	
				Cd	**Pb**
Heat / Power Plants	Solid fuels	Addition of fabric filters to coal-fired large combustion plants, ELV = 20 mgPM/Nm^3	4750	523	26
	Liquid fuels	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20 mgPM/Nm^3	83	7	4
Industrial Combustion (incl. Oil Refineries)	Solid fuels	Addition of fabric filters to coal-fired large combustion plants, ELV = 20 mgPM/Nm^3	61	1939	53
	Liquid fuels	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20 mgPM/Nm^3	40	6	3
Coke Ovens		Control of fugitive emission from coke ovens by capturing and filtering, max. PM content COG 50 mg PM/Nm^3	1241	482	112
Iron & Steel, Blast furnaces		Addition of a fabric filter and evacuation to control fugitive emission from blast furnaces, ELV = 20 mgPM/Nm^3	84	97	0.4
Iron & Steel, Sinter Production		Addition of fabric filters to sinter plant stacks, ELV = 20 mgPM/Nm^3	671	166	3
Iron & Steel, Electric Arc Furnace		Addition of fabric filters to control primary and secondary emission from electric arc furnaces, ELV = 15 mgPM/Nm^3	946	318	57
Primary Copper Production		Addition of fabric filters, wet ESP or ceramic filters to control stack emission from primary Cu smelters, ELV = 5 mgPM/Nm^3	234	14	3
Primary Zinc Production		Addition of fabric filters, scrubbers or ESP to control stack emission from primary Zn smelters, ELV = 5 mgPM/Nm^3	81	9	3
Primary Nickel Production		Addition of fabric filters to control stack emission from primary Ni smelters, ELV = 5 mgPM/Nm^3	36	[c]	[c]
Chlorine Production [a]		Reduction of Hg emission in Hg-based process, ELV = 0.5gHg/tonneCl2	1	1 (for Hg)	
Cement Production		Application of high performance ESP or FF to control primary emission from cement kilns	156	1294	126
Glass Production		Application of fabric filters or electrostatic precipitators in glass production, ELV = 30 mgPM/Nm^3	9	10	0.2
Road Transport (Exhaust)	Gasoline	Lowering the maximum allowable lead content of unleaded gasoline from 13 to 5 mg/l (assumed effective concentration 1 mg/l)	-	-	0
Clinical Waste Incineration [a]		Prededusting with ESP, lime and activated carbon injection followed by FF to control Hg emission from clinical waste incin., ELV = 0.05 mgHg/Nm^3	1	7 (for Hg)	
Iron & Steel, Oxygen Furnace [b]		Addition of dry ESP or scrubber to control BOF primary emission, additional control of fugitive emission by fabric filters, ELV = 20 mgPM/Nm^3	527	326	6
Primary Lead Production [b]		Addition of fabric filters to control stack emission from primary Pb smelters, ELV = 5 mgPM/Nm^3	60	41	0.4
Total		All of above measures	8981	133	2.9

[a] Source scheduled for evaluation by the 1998 UNECE Protocol on Heavy Metals.

[b] Source included due to uncertainty in source strength of Pb from road transport.

[c] Not estimated.

The possible measures for further Hg emission reduction show comparable cost-effectiveness for all sources (Table S6). Only the cost of Hg reduction in the chloro-alkali industry has a lower than average specific cost, but the potential for further Hg reduction in this sector is small. A fuel switch from heavy fuel oil to natural gas seems to be a relatively cost efficient way to further reduce Hg emission. However, the difficulty with this measure is the uncertainty concerning the fate of the heavy fuel oil not fired in these combustion plants. A more expensive reduction measures is injection of activated carbon to large coal-fired combustion plants. This source has a large Hg emission reduction potential. The injection of activated carbon will also have co-benefits due to the removal of specific other gaseous compounds, such as dioxins, provided that the abated Hg source is also a source of other gaseous pollutants.

Table S6 Selected source categories, fuel type, proposed measures, costs and emission reduction of implementing a possible revised HM Protocol aiming at specific Hg reduction (Package 2) on 2020 Hg emissions in UNECE-Europe.

Source Category	Fuel	Applied measure Stage 2	Cost (M€/year)	Hg Emission Reduction (tonnes/yr)	Cost effectiveness Hg (€/g)
Heat / Power Plants	Solid fuels	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% removal efficiency	14496	96.5	150
	Liquid fuels	Fuel switch from heavy fuel oil to natural gas	421	6.3	67
Industrial Combustion (incl. Oil Refineries)	Solid fuels	Specific removal of Hg from coal-fired large combustion plants by njection of activated carbon, 80% removal efficiency.	796	4.7	168
	Liquid fuels	Fuel switch from heavy fuel oil to natural gas	201	2.8	71
Cement Production		Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05 mgHg/Nm^3	2617	18.2	144
Chlorine Production		Complete conversion from Hg-based to Hg-free process	29	2.6	11

In terms of costs per kg HM emission avoided, the possible measures suggested for a revision of the HM Protocol as discussed in this study are expensive compared to the 1998 HM Protocol. Berdowski et al. (1998) estimated the costs of implementation of the first draft of the UNECE HM Protocol. They estimated that, when autonomous developments (e.g. the 2nd S Protocol) where taken into account, the total annual implementation costs were ~ 440 million ECU (1995). The Package 1 revision of the HM Protocol as proposed in this study would bring about annual costs more than ten times as much (€7.6 billion (2000)). For example, the implementation of the draft 1998 HM Protocol would result in overall specific costs of €2 – 3 (1995)/g Cd avoided (Berdowski et al., 1998) whereas the possibly revised Protocol regarded in this study has an average costs effectiveness of €120 (2000) /

g Cd avoided. However, this is as expected because the most cost-effective measures are implemented first. If only measures with specific costs below 10 € / g Cd avoided would be selected for a revision of the HM Protocol ~50% of the total reduction potential (about 40 tonnes Cd) could be reached. Although a revision of the HM Protocol appears costly compared to the 1998 HM Protocol, the costs are still well below the costs of implementation of the 2nd S Protocol. A final remark is that full implementation of the 1998 HM Protocol brings about the biggest step in reduction of HM emissions; a possible revision of the HM Protocol is a further improvement and should be seen in this perspective.

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1. Introduction

Heavy metals are natural components of the earth's crust. Heavy metals are emitted into the atmosphere from anthropogenic activities. Predominantly, these emissions are from combustion processes (power generation, road transportation), industrial sources (iron and steel industry, non-ferrous metal industry) and waste incineration. Metal emissions arise from trace concentrations in fuels, which are burnt, and from the industrial processing of raw materials. They enter the atmosphere as vapour or particulates (dust) or as both. Upon entering the atmosphere heavy metals may be transported over long distances away from source and in certain forms can have an adverse effect on human health and the environment. The impact on humans and animals can be seen in the deterioration of the immune system, the metabolic system and nervous system. Some heavy metals are known carcinogens.

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 (TF) on Heavy Metals. 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. In 2003 the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has asked TNO to execute a study consisting of two phases.

- Phase I of the study was completed in August 2005 and 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 (Denier van der Gon et al., 2005).
- Phase II comprises an estimation of the emission reduction as well as costs of options for a possible revision of the HM/POP Protocols. The options to be considered in Phase II are based on information made available to 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 study "Materials for consideration in the discussion concerning the Protocol on Heavy Metals to the Convention on Long-range Trans-boundary Air Pollution", prepared by IFARE (Rentz et al. 2004a) in cooperation with Germany as TF leader provided the TF HM with a comprehensive overview of current emission levels, limit values, abatement measures and their costs for heavy metals emissions for the sectors covered by the

Protocol.
This study is an important source of information frequently used and underpinning the current study. 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

Options to revise the HM Protocol are proposed and the annual cost and emission reduction due to a possibly revised HM Protocol is to be estimated. The emission reduction and costs of the selected measures will be estimated for the year 2020. Total annual cost by measure, by sector and by country, and the emission reduction by substance will be presented.

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. In view of the envisaged revision of the Technical Annexes to the Protocol on Heavy Metals several reports and notes have been prepared (e.g. Rentz et al., 2004a). The documents provided in this framework are the starting point for drawin up a list of possible additional measures.

1.2 Substances and Countries covered by the study

The impact of a revision of the HM Protocol 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. Furthermore, the effects on particulate matter emission (PM_{10} $PM_{2.5}$) of the additional 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.

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 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.

1.3 Structure of the report

The methodology of the study is outlined in Chapter 2. This includes source selection and a brief presentation op the projected remaining emissions in 2020 after full implementation of the HM Protocol which is the starting point of this study. Chapter 3 discusses selected source-specific measures and their associated costs by individual source category. The results are presented and discussed in Chapter 4. Conclusions from this work are in fact the summarized results. Therefore these are integrated into a "summary and conclusions" chapter presented at the beginning of this report.

2. Methodology

The aim of the study is to assess the emission reduction and costs of a revision of the HM Protocol. In this chapter we first present the starting point for this assessment, being the remaining HM emissions after all countries have implemented the current UNECE 1998 HM Protocol. Next, the procedure to select sources possibly to be addressed in a revision of the Protocol is described. Additional information or choices needed to actually calculate emission reductions and costs are discussed. The selected measures to be investigated are described in chapter 3.

2.1 UNECE heavy metal emissions in 2020 and autonomous measures considered

The remaining HM emissions upon full implementation of the HM Protocol and other autonomous measures are derived from Denier van der Gon et al. (2005).The estimated remaining emissions upon full implementation of the HM Protocol are not only affected by the emission limits and reduction measures laid out in the Protocol but also several autonomous measures that are relevant for varying groups of countries are included. The autonomous measures taken into account are described in more detail in Denier van der Gon et al. (2005) and summarized briefly here. The autonomous measures considered for the year 2020 baseline HM emissions are full implementation of:

- The 1998 UNECE HM Protocol
- The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions
- Integrated Pollution Prevention and Control (IPPC) EU Directive.
- Limitation of emissions into the air from large combustion plants (LCP)
- EC Directive on the incineration of waste.

The basis for calculation of potential emission reductions upon revision of the UNECE HM Protocol are the emissions summarized by country in Table 3.

Table 3 Projected annual emissions of heavy metals in UNECE-Europe by country in 2020 following IIASA CLE-BL scenario and assuming all UNECE countries implement the HM Protocol before 2010 (BL_CLE_FIHM; Denier van der Gon et al., 2005).

ISO3	Cd	Hg	Pb	As	Cr kg/yr	Cu	Ni	Se	Zn
ALB	190	193	6083	155	493	1626	5476	117	4232
ARM	142	194	1142	103	403	685	4160	154	2618
AUT	1432	1210	14816	2821	9741	38417	25833	1481	250095
AZE	2702	1153	16654	2684	6718	6134	119717	2377	18863
BEL	1583	1460	78203	1490	9554	21132	23849	2114	115617
BGR	4244	3587	68043	1011	2938	9474	13126	11644	40743
BIH	602	1552	15576	577	509	3762	4651	314	19496
BLR	906	400	38806	2616	3832	10155	99190	5344	59330
CHE	3037	2271	122507	750	3702	21674	6789	301	680738
CYP	725	778	6251	718	1829	2104	31251	615	2751
CZE	991	2357	11169	2348	4306	22016	14703	4256	104580
DEU	21571	40234	647079	33587	61685	328887	114784	21643	1982015
DNK	701	1837	5861	470	3311	12223	5852	1056	67626
ESP	6850	13837	163870	18488	15315	113689	24468	23936	700703
EST	198	344	14203	1920	1786	2216	2902	323	12579
FIN	1394	526	38300	4495	15305	21975	16711	3711	79833
FRA	7859	14194	179014	20444	160292	188634	158743	8530	1549390
GBR	4691	5290	100605	17929	24574	18685	54241	8845	287168
GEO	262	305	10181	211	676	3692	7447	150	4613
GRC	2249	7004	8485	2216	14814	18720	66532	1311	79500
HRV	601	375	8260	379	2525	11743	10995	400	88800
HUN	2563	3033	33897	2698	2879	20890	18702	475	38688
IRL	764	1351	6478	722	1478	10199	15380	497	30653
ISL	84	87	172	73	176	464	3747	44	2862
ITA	6607	8931	812905	25773	19331	48247	38763	34293	973348
KAZ	14410	17051	416719	30134	22918	144317	74780	6455	624659
KGZ	307	672	8272	286	844	1941	4277	224	10822
LTU	1488	620	28357	811	2041	12995	14433	905	134915
LUX	57	293	4018	53	247	1618	390	27	46163
LVA	366	453	1109	671	4849	2616	8935	393	18876
MDA	324	131	3266	239	489	1569	5488	1654	8268
MKD	4582	1664	28340	345	473	2182	3635	96	206665
NLD	1174	412	38059	960	5848	14871	49462	1178	124380
NOR	975	1202	7539	2291	5405	24005	36564	516	83343
POL	20627	21361	224645	16508	31115	105133	86464	19498	794350
PRT	2472	6655	20501	2515	7890	23267	63073	15152	113789
ROM	4432	9115	101278	2058	5495	20874	56505	7896	144271
RUS	62518	86531	1558887	82677	360816	582690	1019824	60986	2556553
SVK	3168	3700	27542	3156	2482	11284	10698	2655	29310
SVN	1415	584	12866	304	649	4040	3543	191	15031
SWE	329	1257	13713	879	4891	17405	11335	911	299756
TUR	9804	25524	314476	9864	25499	87969	168846	27882	398530
UKR	12698	21592	500061	17682	48477	113189	105073	11688	909508
YUG	2623	4659	42894	2026	1735	16556	10380	2220	49491
Total (tonnes/year)	*217*	*316*	*5761*	*318*	*900*	*2126*	*2622*	*294*	*13766*

2.2 Selection of sources for a possible revision of the HM Protocol

2.2.1 Chlor-alkali plants and medical waste incinerators

The 1998 UNECE Protocol on Heavy Metals requires Parties to evaluate Emission Limit Values (ELVs) for existing chlor-alkali plants and for mercury-containing emissions from medical waste incinerators (MWIs) within two years after the date of entry into force of the Protocol (Annex V, paragraphs 19 and 23(c)). The HM Protocol entered into force on December 30, 2003 and these two sources are by definition included in the current study. Rentz et al. (2004b,c) supplied background information on these sources.

2.2.2 Selection of other sources based on source contributions in 2020

The contribution of the individual source sectors after full implementation of the HM Protocol and implementation of foreseen autonomous measures in 2020 has been calculated for the total UNECE Europe domain (Annex 1). To select the HM sources to be addressed for a possible revision of the HM Protocol we have used the following criteria:

- The contribution to the total emission of one or more of the three priority metals (Cd, Hg and Pb) exceeds 5%
- The contribution to the total emission of one or more of the other heavy metals exceeds 15%
- Emissions from domestic / residential sources are not considered for revision of the HM Protocol
- Sources that are scheduled for re-evaluation by the Protocol will be included (HM emissions from Chlor-alkali industry and Medical Waste Incineration)

A keysource analysis is made of the sources contributing to the HM emission in UNECE Europa in 2020 (Table 3) and presented in Annex 1. Based on this keysource analysis and the criteria outlined above the source categories listed in Table 4 are potentially suitable candidates for a possible revision of the HM Protocol.

A small extension to this list has been made because the contribution of road transport to the total emission of Pb is surrounded by considerable uncertainty. If countries did not officially submit an emission of Pb from road transport, the default emission was estimated by Denier van der Gon et al. (2005) using the fuel quality Directives for UNECE and EC, which state that the Pb content of unleaded gasoline shall be below 0.013 and 0.005 mg Pb/l gasoline, respectively. Since no detailed survey data were available Denier van der Gon et al. (2005) used the

UNECE HM Protocol fuel quality limit value as a worst case emission factor for non-EU countries to be replaced by country data whenever available. However, this assumption influences the outcome of the emission projection substantially (see also Phase I report) because the official emission data are still quite incomplete. It is quite likely that this worst case approach overestimates real-world Pb emissions from road transport. Hence we have reckoned with the possibility that actual Pb emission from road transport may be lower. This implies that potentially the *relative* contribution of other Pb sources may be higher. To avoid that the analysis performed in the current study would not include the relevant sources if the Pb emission estimate of road transport declines due to more accurate information in the near future, iron and steel oxygen furnaces, with a contribution just below 5% of the total Pb emissions, has been included in the selection of sources under consideration for revision of the Protocol (Table 4).
The sources listed in Table 4 cover 74-86% of the priority HM emissions and 64-94% of the other HM (first two rows, Table 5). Note that this indicates the potential for reduction, not the actual reduction that will be achieved. For all HM the contribution of residential sources is ~10% (3-15%). This source sector will be briefly discussed separately in the report but is not included in the list of possible measures for a revision of the HM Protocol and associated calculations.

Table 4 Selected source categories for possible further HM emission reduction.

Source categories to be addressed based on key source criteria	
Heat / Power Plants	Primary Copper Production
Heat / Power Plants	Primary Zinc Production
Industrial Combustion	Primary Nickel Production
Industrial Combustion	Primary Lead Production
Iron & Steel, Blast furnaces	Chlorine Production
Iron & Steel, Sinter Production	Cement Production
Iron & Steel, Electric Arc Furnace	Glass Production
Coke Ovens	Road Transport (Exhaust)
Iron & Steel, Oxygen Furnace[a)]	Medical Waste Incineration

a) Covering 4.4% of total Pb emission, added because of uncertainty concerning Pb emission source strength from traffic.

Table 5 Share of the sources addressed by additional measures and the residential / domestic sector to total HM emissions after full implementation of HM Protocol

	Cd	**Hg**	**Pb**	**As** **%**	**Cr**	**Cu**	**Ni**	**Se**	**Zn**
Selected measures	72	85	83	79	90	63	79	94	73
Additional Pb measure	2.2	0.2	4.4	0.9	1.1	0.7	0.2	0.1	4.6
Residential / domestic sources	16	8.3	4.6	10	5.3	11	10	3.4	7.8
Sum of above categories	90	93	93	91	96	75	89	97	85

Note: The share does not equal the reduction that will be achieved upon implementation of additional measures.

2.3 Emissions to air in 2020 assuming full implementation of the 1998 HM Protocol and foreseen autonomous developments

The starting point for the identification of measures to revise the HM Protocol and subsequent quantification of emission reductions and costs is the selection of sources based on contributions to the 2020 HM emissions assuming full implementation (all European UNECE countries) of the current HM Protocol and implementation of all foreseen autonomous developments (Table 3). The additional reduction in HM emissions due to a revision of the HM Protocol is partly determined by autonomous measures that are to be implemented depending on the obligations of each specific country. To keep an overview, countries have been aggregated in country groups according to the foreseen reduction measures and policies that apply for each country determining the representative PM and HM concentrations in the first phase of this study. For sources (Table 4) to be considered for a revision of the HM Protocol, the assumptions on PM concentrations as they have been made in Phase I of this project (Denier van der Gon et al., 2005) are summarized in Table 6 for three country groups. For the chloro-alkali industry the country grouping is different as the most important distinction between countries is the membership of EuroChlor (Table 7). Companies that are EuroChlor members have committed themselves to the EuroChlor voluntary reduction program for mercury emissions in the Chlor-alkali-industry. The most stringent policy for country group I (EU(25) plus Norway and Switzerland, abbreviated as EU(25)+) is the EU IPPC Directive, whereas for group II and III the HM Protocol determines the PM concentration, except for large combustion plants where the 2nd Sulphur Protocol brings about the lowest PM stack concentrations. The concentration data in Table 6 are the values that were considered to be the best approximation of average actually achieved concentrations in 2020 after implementation of both foreseen autonomous policy and the HM Protocol (Denier van der Gon et al., 2005). In the present study, the importance of autonomous measures other than EU Directives is limited and in our final summaries only EU(25)+ and non-EU(25)+ will be presented separately.

Table 6 *Estimated[a)] PM concentrations (mg/Nm^3) after full implementation of HM Protocol and implementation of foreseen autonomous measures, by country group as derived by Denier van der Gon et al. (2005).*

Source Category	Country grouping		
	EU(25)+	non-EU+2nd S	non-EU, no 2nd S
Combustion plants > 50 MWth, solid fuels	20	20 – 30	50
Combustion plants > 50 MWth, liquid fuels	40		50
Coke Ovens	50	100	
Iron & Steel, Blast furnaces	20	50	
Iron & Steel, Sinter Production	40	50	
Iron & Steel, Oxygen Furnace	20	100	
Iron & Steel, Electric Arc Furnace	20		
Primary Copper Production	10	20	
Primary Zinc Production	20		
Primary Nickel Production	20	100	
Primary Lead Production	10		
Cement Production	30	50	
Cement Production	~ 0.063[b)]		
Glass Production, PM	20	100	
Road Transport (Exhaust, gasoline-fuelled vehicles)	5, 13[c)]		
Medical Waste Incineration	~ 0.082[b)]		

a) Concentration and size fractions are based on data from Phase I and CEPMEIP background information

b) Value refers to mg Hg/Nm^3

c) Values refers to mg Pb/l gasoline

Table 7 *Mercury emission by the Chloro-Alkali industry after full implementation of HM Protocol and implementation of foreseen autonomous measures by country group.*

Source Category	Country grouping	
	Eurochlor members	non- Eurochlor members
	mg Hg/tonne chlorine	
Chlorine Production	0.5	2

2.4 Proposed ELVs for a revision of the HM Protocol.

For the sources to be considered for revision of the HM Protocol representative emission limit values (ELVs) have to be determined. The German/French IFARE has compiled an overview of recent information on the performance of advanced emission reduction technologies for heavy metals (Rentz et al., 2004a). Here we select new ELVs based on information submitted by IFARE to the Task Force on Heavy Metals. These more strict ELVs could then replace those that are currently in the Protocol upon a possible revision of the Protocol. However, some small adjustments or additional assumptions are needed when proposing new possible, realistic and feasible ELVs.

The use of the information provided by Rentz et al. (2004a) is limited to the PM ELVs only, with the exception of a few Hg emission limit values. However, Rentz et al. (2004a) occasionally provide separate values for Pb and Cd emissions as well (e.g. Table 8). In the present study it is difficult if not impossible to work with separate Pb and Cd limit values as separate costs are not available, monitoring of the HM content is not performed, and the EU BREFs made for the EU IPCC Directive only contain PM limits.

Table 8 Example of limit values for individual HM for Iron & Steel, Blast furnaces.

	Emission limit values for Blast furnaces in Iron & Steel industry		
Source	**TNO (2005)**	**Rentz et al. (2004)**	**ELVs (BREF)**
Species	30 mg/m^3 (PM)	10 mg/m^3 (PM); 0.5 mg/m^3 (Pb); 0.05 mg/m^3 (Hg); 0.05 mg/m^3 (Cd)	<10 mg/m^3 (PM, Hot stoves); <10 mg/m^3 (PM, BFG cleaning); 1-15 mg/m^3 (PM Casting bay area, fugitive)

2.4.1 Choice of emission strength after implementation of BAT

The BREF documents that describe the Best Available Technologies (BAT) often present a range instead of an absolute value as representative emission strength after implementation of BAT. For example, for an important HM emission source such as the heat and power plants, the BREF documents that describe the 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. However, in the present study it is necessary to work with fixed values instead of ranges to calculate clear emission reductions and cost effectiveness.

In a joint meeting with the project sponsor and two independent experts it was decided to take the upper limit of BAT ranges as representative emission strength after implementation of BAT. This will result in feasible, proven emission strengths and subsequent emission reduction but implies we do not go for maximum ambition level in terms of future HM emission reduction. The arguments to take the upper limit of BAT ranges as representative emission strength were:
- The upper limit of the ranges is generally proven and does not build on or depend on (unpredictable) future developments.
- Often the achieved emission strengths will be lower than the upper value upon implementation of BAT but in cases of high emission reduction efficiencies (very) short periods of malfunctioning may have a large impact on the average emission strength, hence the upper limit may be more realistic for the annual average.

- The investment costs for the lower limit of the ranges is often difficult to estimate as it often demands re-building of the facility instead of added “end-of-pipe” technologies.
- New facilities may and should directly go for a higher ambition level but the aim is to have the calculated emission reductions and cost effectiveness generally applicable, meaning also for all existing facilities
- In various cases the costs to achieve the lower value of the BAT ranges may be very high resulting in unrealistic investment costs. In a particular (new) facility the choice for lowest emission strength may be realistic but not across the board.
- At the moment of this writing a large gap exists between measured and modeled HM & POP deposition levels (Slootweg et al., 2005). As long as we cannot fully understand and guarantee that (extremely) high investments will definitely solve the problem of exceeding critical loads, it is felt some caution is needed.
- For a few cases where, in a later package, it is expected that lower emission strengths are realistic without huge additional costs, a sensitivity run could be done to get the additional emission reduction.

The information on ELVs proposed by various studies for the selected HM sources and the relative contribution of these sources to HM emissions in UNECE Europe in 2020 is summarized in Table 9 and Table 10. The last column of both tables provides the ELVs that will be used in this study to evaluate costs and emission reduction due to a possible revision of the HM Protocol.
The measures considered for a possible revision of the HM Protocol in this study are separated in a Package 1 (Table 9) and Package 2 (Table 10) proposal. Package 1 focuses on (further) dust removal, the more traditional way to reduce emissions of HM. Mercury is often poorly mitigated by such general HM reduction measures which focus on dust removal and dust emission limit values. Therefore, the Package 2 proposal specifically addresses Hg emissions that are poorly mitigated by the tightening of the dust ELVs outlined in Package 1. In general Package 2 measures are more expensive. However, in some cases (e.g. a proposed fuel switch from fuel oil to gas) a Package 2 measure will make the Package 1 measure for a particular source redundant.

Table 9 *Emission limit values proposed by various studies for selected HM sources, the relative contribution of these sources to HM emissions and the emission limit values proposed as Package 1 revision of the HM Protocol in the present study.*

Source Category	Fuel	Revisions proposed by: TNO HM Study	IFARE Annex V	BREF Range	Source contribution to total HM emissions in 2020 (%): Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Proposed limit value Stage I
Heat / Power Plants	Solid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas;	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM); 0.03mg/m3 (Hg)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**8.3**	**38.2**	**6.7**	**26.6**	3.8	14.8	3.6	**16.4**	**18.3**	20mg/m3 (PM, all plants >50MWth)
	Liquid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas; Limit HM content fuel	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**9.8**	2.1	0.8	5.1	3.7	1.1	**32.3**	5.1	0.0	20mg/m3 (PM, all plants >50MWth)
Industrial Combustion	Solid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM)	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM); 0.03mg/m3 (Hg)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	3.0	**6.7**	4.0	9.8	4.9	4.1	3.8	3.2	5.7	20mg/m3 (PM, all plants >50MWth)
	Liquid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas; Limit HM content fuel	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**7.2**	1.1	0.6	6.9	2.5	0.8	**17.6**	3.5	0.1	20mg/m3 (PM, all plants >50MWth)
Coke Ovens	-	Limit PM content fuel of COG; 50mg/m3 (PM) gaseous releases			**6.8**	2.5	1.1	1.4	2.3	1.0	0.4	0.0	0.4	50mg/m3 (PM in COG); limit fugitive releases
Iron & Steel, Blast furnaces	-	30mg/m3 (PM)	10mg/m3 (PM); 0.5mg/m3 (Pb); 0.05mg/m3 (Hg); 0.05mg/m3 (Cd)	<10mg/m3 (PM, Hot stoves); <10mg/m3 (PM, BFG cleaning); 1-15mg/m3 (PM Casting bay area, fugitive)	1.6	1.1	**14.4**	8.9	2.3	7.7	1.4	1.7	**18.4**	10mg/m3 (PM, BFG); 20mg/m3 (PM, Casting bay evacuation)
Iron & Steel, Sinter Production	-	30-40mg/m3 (PM)	20mg/m3 (PM); 1mg/m3 (Pb); 0.05mg/m3 (Hg); 0.05mg/m3 (Cd)	<50mg/m3 (PM, ESP); 10-20mg/m3 (PM, FF)	4.5	1.1	**9.4**	2.7	4.0	5.3	3.7	1.0	1.4	20mg/m3 (PM)
Iron & Steel, Electric Arc Furnace	-	10mg/m3 (PM)	5mg/m3 (PM); 0.1mg/m3 (Hg)	<5mg/m3 (PM, New plant); <15mg/m3 (PM, Existing plant); >98% removal fugitive PM emission	**9.4**	0.1	2.0	1.6	2.3	1.8	0.1	1.2	8.4	15mg/m3 (PM)
Primary Copper Production	-	10mg/m3 (PM)	5mg/m3 (PM); 1mg/m3 (Pb); 0.05mg/m3 (Hg)	1-5mg/m3 (PM)	**10.7**	0.1	1.9	13.8	0.0	**18.6**	0.0	0.0	4.5	5mg/m3 (PM)
Primary Zinc Production	-	10mg/m3 (PM)	5mg/m3 (PM); 1mg/m3 (Pb); 0.05mg/m3 (Hg)	1-5mg/m3 (PM)	**5.4**	1.6	0.6	0.0	0.0	0.0	0.0	0.0	12.5	
Primary Lead Production	-		2mg/m3 (PM)	1-5mg/m3 (PM)	1.4	1.1	**5.6**	0.3	0.0	0.2	0.0	0.0	0.2	5mg/m3 (PM)
Primary Nickel Production	-	10mg/m3 (PM)			0.0	0.0	0.0	0.0	**61.3**	0.0	14.0	0.0	0.0	5mg/m3 (PM)
Chlorine Production *	-		1g/Mg Cl2 (Hg, Mercury cell process); 1.2g/Mg Cl2 (Hg, Hg Cells-Simultanious production of alkali lye, dithionite or alcoholates); Hg free for new plants	0.2-0.5g/Mg Cl2 (Hg)	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5g/Mg Cl2 (Hg)
Cement Production	-	Limit content fuel (Hg)	20mg/m3 (PM); 0.05mg/m3 (Cd)	20-30mg/m3 (PM)	1.3	**28.8**	0.6	1.4	0.9	0.0	0.7	0.2	0.5	30mg/m3 (PM); 0.05mg/m3 (Hg)
Glass Production	-		20mg/m2 (PM) or 0.2kg/hr; 3mg/m3 (Pb); 0.8mg/m3 (Pb, container glass using cullet); 0.2mg/m3 or 0.5kg/hr (Cd)	5-30mg/m3 (PM); <5mg/m3 (Pb)	0.9	0.3	2.1	0.9	1.7	0.5	0.6	**61.3**	1.4	30mg/m3 (PM)
Road Transport (Exhaust)	Gasoline	5mg/l (Pb)			1.3	0.0	**33.8**	0.0	0.3	7.3	0.4	0.3	1.0	5mg/l (Pb)
Clinical Waste Incineration *	-		10mg/m3 (PM) (UNCHANGED); 0.03mg/m3 (Hg); 0.05mg/m3 (Cd, Ta); 0.5mg/m3 (Pb)	<25mg/m3 (PM, ESP); <5mg/m3 (PM, FF); <0.03mg/m3 (Hg, Activ. carbon inj.)	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	10 mg/m3 (PM), 0.03mg/m3 (Hg)
Iron & Steel, Oxygen Furnace *	-	10-20mg/m3 (PM)	20mg/m3 (PM); 0.5mg/m3 (Pb); 0.05mg/m3 (Hg); 0.05mg/m3 (Cd)	20-30mg/m3 (PM, ESP, Prim. & sec. dedusting); 5 15mg/m3 (PM, FF, Prim. & sec. dedusting)	2.2	0.2	***4.4***	0.9	1.1	0.7	0.2	0.1	4.6	20mg/m3 (PM)
Residential, commercial and other combustion	Solid fuels	Type approval new units; Replacement by natural gas			**5.7**	3.2	2.5	7.3	3.1	7.8	5.1	2.3	5.2	Not Selected
	Liquid fuels	Limit HM content fuel; Replacement by natural gas			**6.2**	0.2	0.9	2.9	0.5	0.3	4.3	1.0	0.1	Not selected

* Emission Limit Values of Source scheduled for evaluation by the 1998 UNECE Protocol on Heavy Metals – selection is not based on keysource analysis

** One additional lead source t just below 5% contribution to total Pb 2020 emission has been included due to uncertainty in source strength of Pb from road transport

Table 10 Emission limit values proposed by various studies for selected HM sources, the relative contribution of these sources to HM emissions and the emission limit values proposed as Package 2 revision of the HM Protocol in the present study.

Source Category	Fuel	Revisions proposed by: TNO HM Study	IFARE Annex V	BREF Range	Source contribution to total HM emissions in 2020 (%) Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Proposed limit value Stage II
Heat / Power Plants	Solid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas;	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM); 0.03mg/m3 (Hg)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**8.3**	**38.2**	**6.7**	**26.6**	3.8	14.8	3.6	**16.4**	**18.3**	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.
	Liquid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas; Limit HM content fuel	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**9.8**	2.1	0.8	5.1	3.7	1.1	**32.3**	5.1	0.0	Fuel switch from heavy fuel oil to natural gas
Industrial Combustion	Solid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM)	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM); 0.03mg/m3 (Hg)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	3.0	**6.7**	4.0	9.8	4.9	4.1	3.8	3.2	5.7	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.
	Liquid fuels	5-50MWth 50mg/m3; >50MWth 30mg/m3 (PM); Replacement by natural gas; Limit HM content fuel	50-100MWth 20mg/m3 (PM); >100MWth 10mg/m3 (PM)	10-20mg/m3 (PM, 50-100MWth); 5-15mg/m3 (PM, 100-300MWth); 5-10mg/m3 (PM, >300MWth); <0.03mg/m3 (Hg)	**7.2**	1.1	0.6	6.9	2.5	0.8	**17.6**	3.5	0.1	Fuel switch from heavy fuel oil to natural gas
Chlorine Production	-		1g/Mg Cl2 (Hg, Mercury cell process); 1.2g/Mg Cl2 (Hg, Hg Cells-Simultanious production of alkali lye, dithionite or alcoholates); Hg free for new plants	0.2-0.5g/Mg Cl2 (Hg)	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Complete conversion from Hg-based to Hg-free process
Cement Production	-	Limit Hg content fuel (Hg)	20mg/m3 (PM); 0.05mg/m3 (Cd)	20-30mg/m3 (PM)	1.3	**28.8**	0.6	1.4	0.9	0.0	0.7	0.2	0.5	Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05 mgHg/Nm3

The associated PM size data for the proposed emission limit values for Package 1 (Table 9) and Package 2 (Table 10) for the sectors listed in Table 4, have been approximated and tabulated in Table 11 (when applicable). The particle size differentiation is based on background information of the CEPMEIP PM inventory (Visschedijk et al. 2004). This information is needed to compensate for enrichment effects and calculate the reduction of metals from dust reduction factors as has been described by Denier van der Gon et al. (2005).

The last column (5^{th}) of Table 11 presents an indication of the type of measure that is expected to be needed to comply with the revised ELVs in case the current ELV or achieved concentration is less stringent or higher. A further elaboration on how in a technical sense the revised ELVs can be achieved is presented in Chapter 3. Note that several sectors (large combustion plants and the production of chlorine and cement) are listed twice. For these sectors, two different measures will be evaluated (e.g. a general reduction of dust (Package 1) followed by a further specific reduction of Hg (Package 2)).

Table 11 Proposed limit values in the present study and associated PM size data.

Source Category	mg PM/Nm^3	PM10 (-)	PM2.5 (-)	Measure(s) needed / considered
Combustion plants > 50 MWth, solid fuels	20	0.95	0.75	Further reduction of PM stack emission
Combustion plants > 50 MWth, solid fuels	η Hg = 80%	N/A	N/A	Additional specific reduction of Hg
Combustion plants > 50 MWth, liquid fuels	20	1	0.9	Reduction of PM stack emission
Combustion plants > 50 MWth, liquid fuels	0	N/A	N/A	Replacement of fuel oil by natural gas
Coke Ovens	50	0.8	0.5	Control of fugitive PM emission
Iron & Steel, Blast furnaces	20	0.9	0.7	Control of fugitive PM emission
Iron & Steel, Sinter Production	20	0.9	0.7	Further reduction of PM stack emission
Iron & Steel, Oxygen Furnace	20	1	0.95	Further reduction of PM stack emission
Iron & Steel, Electric Arc Furnace	15	0.95	0.7	Further reduction of PM stack emission
Primary Copper Production	5	1	0.9	Further reduction of PM stack emission
Primary Zinc Production	5	1	0.9	Further reduction of PM stack emission
Primary Nickel Production	5	1	0.9	Further reduction of PM stack emission
Primary Lead Production	5	1	0.9	Further reduction of PM stack emission
Chlorine Production [b)]	0.5 [a)]	NA	NA	Specific reduction of Hg
Chlorine Production [b), c)]	0 [a)]	NA	NA	Switch to Hg-free process
Cement Production	30	0.95	0.45	Further reduction of PM stack emission
Cement Production	0.05 [c)]	NA	NA	Additional specific reduction of Hg
Glass Production	30	0.95	0.9	Further reduction of PM stack emission
Road Transport (Gasoline-fuelled vehicles, Exhaust)	5 [e)]	NA	NA	Lowering Pb content
Medical Waste Incineration	0.05 [d)]	NA	NA	Additional specific reduction of Hg

NE means "not estimated"

NA means "not applicable"

a) Limit value refers to mg Hg/tonne chlorine

b) Other country groups apply here (Eurochlor members = Group 4, non-members = Group 5)

c) Conversion to Hg-free process

d) Limit value refers to mg Hg/Nm^3

e) Limit value refers to mg Pb/l gasoline

2.5 The effect of IPPC Directive on projected emissions

The projected emissions for 2020 (Table 3) that are the base-line emissions on which any further emission reduction measures are superimposed, assume implementation of the IPPC Directive for all EU(25)+ Member States as autonomous policy. This implies that in 2020 all major industrial sources of air pollution will use technologies equal or equivalent to BAT as described in the IPPC BREF Documents. The IPPC Directive does not demand meeting certain emission limit values, instead it prescribes the use of certain techniques. Achieved emission as after implementation of these techniques has to be estimated.

Denier van der Gon et al. (2005) estimated the emission concentrations after implementation of the IPPC Directive, based on general characteristics with respect to removal efficiencies of the prescribed technologies, and by taking into account that:

- The BREF documents suggest emission strengths that are indicative of what could be - and in some cases has been - achieved in more or less ‘ideal’ situations
- IPPC states that technologies considered equivalent to what is described in the BREF documents are permissible as well (if for instance proven more effective for a multi-pollutant abatement strategy)
- Early in the text of several chapters, the BREF documents suggest higher residual emissions than what is presented in the concluding sections.

This makes estimation of the actual remaining emission after implementation of the Directive a fairly difficult and to some extent subjective affair.

In the present study (Phase II) the emission after the IPPC Directive is estimated based on information by IFARE (Rentz et al., 2004a, see previous paragraph). Especially for the primary non-ferrous metals production there is a discrepancy between the approach followed in Phase I (Denier van der Gon et al., 2005) and IFARE regarding representative remaining emission strengths. Here IFARE suggests more stringent ELVs (e.g. compare Table 6 “Group1” and Table 11). For example, Denier van der Gon et al. (2005) assumed that for Sinter Production 40 mg PM/Nm^3 is representative for emission control equipment equivalent to BAT and heavy oil-fired combustion plants never go below 40 mg/Nm^3 without end-of-pipe particulate removal (not prescribed by IPPC). IFARE suggests for electric arc furnaces and the non-ferrous metal production sector, very low residual emissions after IPPC implementation (below 20 mg/Nm^3 and far below 5 mg/Nm^3, respectively).

These arbitrary differences are not discussed further as it was decided to follow the well-documented IFARE (Rentz et al., 2004a) suggestions albeit with the specific modification that we select the single upper limit of the BAT range (section 2.4.1).

It should be noted that eventually the same results will be realized due to implementation of the revised ELVs. The difference is in the details; to what extend is the emission reduction attributed to implementation of IPPC or a revised HM Protocol. This also defines which costs are made by implementation of IPPC or a revised HM Protocol; if it is assumed that the suggested emission limit values of the revised Protocol based on Rentz et al. (2004a) will be achieved in 2010 as a result of the implementation of the IPPC Directive, the costs of revising the HM Protocol will be zero for EU(25)+ Member States.

2.6 Spatial distribution of 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 as described in Denier van der Gon et al. (2005).

2.7 Activity data for year 2020

In the first phase of this study emission projection to the years 2010, 2015 and 2020 were made by considering the expected developments of source activity rates following 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); Baseline energy pathway, current legislation without climate policies: BL_CLE_Apr04 (Aug04)). For some source sectors that are important for HM emissions, no projections are made in the framework of the CAFE programme, for these sectors (e.g. waste incineration) a projection to 2010, 2015 and 2020 was made by TNO and described in Denier van der Gon et al. (2005). The emission projections were made by making scaling factors for the future years that were applied to the baseline year 2000 data. However, most of the cost data (see chapter 3) are expressed per ton of produced products therefore actual production in 2020 for HM emitting sectors needs to be estimated not just relative growth. We estimated production capacity based on the assumption that actual production is 70% of the installed capacity.
We then scaled the year 2000 activities using the same scaling factors as derived for the emissions in Phase I. This gives an approximation of the relevant activities in 2020.

3. Selected source-specific measures and their associated costs

Potential measures and their associated costs for HM emission reduction of sources listed in the HM Protocol are discussed in this chapter by source type. A list of possible measures that may be used for a revision of the HM Protocol is compiled following the source selection procedure outlined in chapter 2. The possible measures are basically derived from the following references:

- The IFARE review of the BAT and ELVs for all source categories listed in Annex II to the Protocol (Rentz et al. 2004). The report is available in full at: *http://www-iip.wiwi.uni-karlsruhe.de/forschung/emission_html/UNECE.htm* and was commissioned by Germany as part of its commitment as TF leader to make data available for the TFHM
- The preliminary listing of measures in phase I of the present study (Denier van der Gon et al., 2005) the BAT conclusions of the respective European Reference Document on Best Available Techniques (BREF)
- ENTEC regards costs of meeting future ELVs. Calculations often have current regulations in the EU(15) as a starting point. Current regulations in the EU resemble the current ELVs in the HM Protocol. Further reduction has parallels to tightening Protocol. (Entec, 2001)
- Earlier work by TNO (e.g. Berdowski et al., 1997; 1998)

The potential emission reduction measures are discussed, per source category, in terms of type and cost. A distinction is made between emission control at stationary sources (subdivided in power generation, industrial combustion and process emissions) and the use of certain HM containing products. For most sources the proposed measures bring about a modification to an existing installation in order to meet the new emission limit value. In such case a non-recurring investment has to be made. In this study investment costs, operantional costs and resulting annual costs have been estimated. Firstly, the total capital investment (TCI) of the measure has been estimated based on literature data (see above) and the the annuity (annual capital costs) is subsequently calculated by using:

$$Annuity = \frac{i(i+1)^n}{(1+i)^n - 1}$$

With i = Interest rate (-)
n = Amortisation period (years)

Based on the technical life expectancy of the emission control units, an amortisation period of 20 years is chosen. The calculations are based on an interest rate of 4% (Amann et al., 2005). This results in an annuity of 7.4% (in line with the assumptions in the IIASA RAINS model see e.g. Amann et al., (2005))

The annuity of the TCI is increased by the operational costs in order to come to the total annual costs. The operational costs, comprising fixed operational costs (maintenance, labour, other overhead costs, insurance etc.) and variable operational costs (energy, raw materials) are in some cases estimated by taking a percentage of the TCI. Strictly speaking running costs are dependant on the emission control technique that is used, for instance fabric filters have a somewhat higher operational cost due to frequent replacement of the filter cloth. These differences are neglected due to the overall uncertainty of the cost estimates. In case data on operational costs were lacking, a fixed percentage, being 5%, (4% for the fixed operational costs and 1% for the variable operational costs (Kok, 1997, Berdowski et al., 1998)), has been used in order to estimate the total operational costs.
The costs of possible revison of the HM Protocol are calculated as additional costs on top of the costs of the present HM Protocol (incremental cost). This implies that the difference between the cost of the present ELV and the adjusted ELV will be calculated. Since the costs of a possible revision are estimated assuming full implementation of the HM Protocol and full implementation of autonomous measures, the costs in the EU(25)+ will often appear lower than for other countries because the EU(25)+ countries have to comply with EC Directives and may have already made (a part of) the costs. The costs will be presented as total annual costs (the sum of amortization and operational costs) and are expressed in Euro (€) as of year 2000. However, a clear year of reference for costs of specific measures is often not given and costs have to be seen as an approximation and not the absolute truth – this is further detailed in the next paragraph. When calculating the costs per ton of emission prevented (not-emitted) all costs for a specific measure will be taken into account despite the fact that a measure may generate emission reduction for other substances as well. This is a necessity because it is at present not possible to weigh e.g. an As emission reduction as compared to e.g. Pb emission. However, it is important to note that many measures that target a specific HM have substantial co-benefits as ultimately a whole group of substances (e.g. other metals, particulate matter and/or dioxines) will be reduced.

3.1 Limitations of the cost data used

According to Annex III to the Protocol, the total costs per year per unit abated (including capital and operating costs) should be considered (paragraph 10). In Annex III it is mentioned that the indicated investment and cost figures are highly case-specific and depend on such factors as plant capacity, removal efficiency, raw gas concentration, type of technology, and the choice of new installations as opposed to retrofitting.
For the preparation of the revision of Annex III, Rentz et al., (2004a) collected data on costs for abatement measures where available. However, Rentz et al., (2004a) explicitly note that the new cost data may not be comparable with the existing information in Annex III of the Protocol. Moreover, they state that it is very difficult to give reliable cost data which could be used in a more general sense without

the danger of misleading results and conclude that an accurate comparison of cost data is, in general, not possible (Rentz et al., 2004a). The reasons for incomparability and difficulties in obtaining reliable general applicable cost data listed by Rentz et al., (2004a) obviously also apply to the use of these cost data in the present study.
Because of the importance of understanding the limitation of the cost data underlying the results, these reasons are repeated here:

- Investments and operating costs may be highly influenced by site-specific factors like local prices (for transport, energy etc.), climatic (affecting e.g. energy demand) or financial conditions (taxes, interest rate etc.), just to name a few. Thus, reported financing and operating costs may not be generalized if they include a substantial percentage of site and corporate specific cost components.
- The level of detail for cost information varies widely. While in some cases a detailed cost analysis is given, in others just a rough cost range is indicated.
- Often the basis for calculation is not indicated, e.g. there is no information available if and which amortization period or interest and discount rate, respectively, was employed.

Thus it can be concluded that the costs of emission reduction as indicated in this study give an order of magnitude of the cost range for a specific technology, and allow only a limited comparison of costs between techniques and countries.

3.2 Emission Limit Values re-evaluated under the current HM Protocol.

The 1998 Protocol on Heavy Metals requires Parties to evaluate Emission Limit Values (ELVs) for existing chlor-alkali plants and for mercury-containing emissions from medical waste incinerators (MWIs) within two years after the date of entry into force of the Protocol (Annex V, paragraphs 19 and 23(c)). The French-German Institute for Environmental Research (IFARE) prepared a report, commissioned by Germany, as lead country of the Task Force on HM, reviewing the Best Available Techniques (BAT) and ELVs for controlling emissions of heavy metals and their compounds from existing chlor-alkali plants and from MWIs. (Rentz et al., 2004b, c). As part of the effort to meet its mandate, the Task Force produced a summary of ELVs based largely on IFARE reports. (UNECE, 2005)

3.2.1 Medical Waste Incineration

Emission control techniques for medical waste incineration are similar to those applied in municipal waste incineration. BAT entails the pre-dedusting with an ESP, followed by lime and activated carbon injection and finally a fabric filter.

Specific abatement costs are € 5.73 – 6.06/(tonne/year) for an ESP and € 7.08 – 7.30/(tonne/year) waste for a fabric filter with lime and activated carbon injection. Plant capacities range from 75,000 to 150,000 tonne/year (Rentz et al., 2004b). Information from the US EPA cited by IFARE suggests investment costs ranging from US$ 56,500 – 127,000/(tonne/hour) and operational costs of US$ 84,000 – 89,000/(tonne waste/year). Entec (2001) reports emission control costs for 3 different medical waste incinerators. Capital costs vary from M€ 0.5 to 1.5 and operational costs are between k€ 5 and 100. Adding a fabric filter, limestone and carbon injection to a 1 tonne/h incinerator would result in M€ 1 capital and an annual k€ 100 operating costs (Entec., 2001).

Based on an evaluation of the IFARE and Entec data and assuming an average annual capacity of 90000 tonnes and a load factor of 0.7, the following cost relations have been derived:

Investment costs € 15 / tonne waste (in tonnes/year)
Operational costs € 1.5 / tonne waste (in tonnes/year) . year^{-1}

Costs are calculated for all countries since it is expected that because of their relatively small capacity, most medical waste incinerators will not be equipped with (expensive) Hg control techniques as a result of autonomous measures only.

3.2.2 Chlor-alkali Industry

For the Hg-based process to produce chlorine, Hg that is diffusely emitted from the cells to the cell room is the main source of air emission of Hg. Emission can be reduced by the collection and treatment of Hg-containing gas streams from all possible sources, as well as preventing other fugitive release through good housekeeping and maintenance (Rentz et al., 2004c). IFARE gives cost data for retrofitting emission abatement technologies to existing plants in order to meet an emission limit value of 0.5 g Hg/tonne chlorine capacity. Reported annual costs vary from € 0.9 to 1.3/tonne Cl_2 production capacity for 100,000 tonnes/year plants, depending on the technology used. The removal of Hg from the hydrogen stream would result in an additional M€ 0.5.

Several other examples of costs of emission control measures are given by Entec (2001): Adsorption on activated carbon (capital M€ 1.4, operational M€ 0.2 /year), scrubbing with hypochlorite (M€ 16.4 capital, M€ 1 /year operational).

As can be noted, the reported costs vary considerably. It is expected that investment costs for upgrading a conventional plant to low emission standards would result in at least one to several million Euros per plant as a rough estimate.

Conversion of a Hg-based to a membrane-based process would bring about investment costs of € 220 to 600/tonne chlorine production capacity. The mercury-free membrane and the non-asbestos diaphragm process are considered BAT (Rentz et al., 2004c).

Recapitulating, meeting the 0.5 g Hg/tonne limit value is estimated to cost around:

€ 20 / tonne production capacity (in tonnes/year), investment
€ 1 / year · tonne production^{-1} (tonnes/year) operational

€ 500 / tonne production capacity (in tonnes/year)

Members of Eurochlor have indicated that by the year 2020 all chlorine production plants of Eurochlor members are expected to have abandoned the Hg process. Costs are therefore estimated only for non-Eurochlor members.

3.3 Sinter plants

IFARE considers the application of an additional fabric filter after an existing ESP, scrubber of cyclone as BAT for controlling PM emissions from sinter plants (Rentz et al., 2004a). It is affirmed by Entec in (2001) that based on the BREF documents, the use of additional fabric filters (through retrofit) might be the best long term solution for achieving PM concentrations below 20 mg/Nm^3.

Abatement costs for an additional fabric filter on a sinter plant are € 5-15/ (Nm^3/h) (investment) and € 0.25-1.5/1,000 Nm^3 treated (operational) (Rentz et al., 2004a). Abatement costs are also given by Entec (2001). Capital costs are reported to be M€ 7 to 22 (2000) for 1,000,000 m^3/h waste gas flow. Operational costs vary from M€ 2 to 14/year for a 4 Mtonnes/year production plant. Note that the reported operational costs of this fabric filter seem relatively high compared to what is reported for other sources.

In order to reduce stack concentrations from 40 – 50 mg/Nm^3 to 20 mg/Nm^3, an additional fabric filter would be required. Based on an average of the above mentioned cost data and engineering information for an average sinter plant, we have derived the following specific investment and operational costs relations:

Investment costs € 2.5 / tonne production capacity (in tonnes/year)
Operational costs € 2 / tonne production capacity (in tonnes/year) · year^{-1}

It is expected that after the implementation of the IPPC Directive in the EU(25), the average sinter plant still not always achieves 20 mg/Nm^3. Therefore costs are calculated for all three country groups (1, 2 and 3).

3.4 Blast furnaces

The options available to apply further emission reduction to blast furnaces address the dedusting of top gas and tap holes and runners. BAT for blast furnace gas dedusting is mechanical pre-separation followed by an efficient scrubber or a wet ESP. Fugitive emission from the tap holes is to be abated by evacuation and subsequent dedusting with a fabric filter (Rentz et al., 2004a). According to IFARE, the dedusting of top gas is in existing plants usually quite efficient already and further measures should focus on minimizing fugitive emission.

IFARE specifies the costs of a 690,000 Nm^3/h bag filter system to control fugitive emission to be in the range of M€ 1 to 2.3 for the investment and € 0.5 to 2.8/tonne for the operational costs (3 Mtonnes/year plant). Note the relatively high operational costs.

In order to reduce concentrations from 50 mg/Nm^3 to 20 mg/Nm^3, an additional fabric filter would be required to control fugitive emission. Based on an average of the above mentioned cost data, we have derived the following specific cost relations for investment and operational costs:

Investment costs € 0.55 / tonne production capacity (in tonnes/year)
Operational costs € 0.55 / tonne production capacity (in tonnes/year) · $year^{-1}$

Costs are calculated for non-EU(25)+ countries since it is expected that the more stringent proposal for a revised Protocol ELV will be met as a result of the implementation of the IPPC Directive.

3.5 Basic oxygen furnaces

IFARE and Entec distinguish three relevant emission points within a BOF, being hot metal pre-treatment (before and during loading), primary dedusting (waste gas from furnace) and secondary dedusting (from casting bay gas evacuation). The emission limit value to be introduced by the Protocol would refer to the furnace waste gas and the fugitive releases from the casting bay, with PM concentrations of both gas streams below 20 mg/Nm^3.

According to IFARE, the first source type (furnace waste gas) can be effectively controlled by dry ESP or scrubbing, with both techniques achieving concentrations of 10 to 50 mg/m^3. Capital costs are M€ 24 to 40 (1996) for a 1 Mtonnes/year production while operational costs are reported to be € 2 to 4/tonne (1996).

Secondary dedusting would be best achieved by using suction hoods connected to fabric filters or ESP (Rentz et al., 2004a, Entec 2001). Both techniques could reduce concentrations to 20 mg/m^3 or lower. Capital costs for a complete air cleaning system according to above discussed specification would be M€ 12 to 20 (1996) for a 1 Mtonnes/year plant. Operational costs are € 0.8 to 4/tonne (1996).

In order to reduce primary release concentrations from 100 mg/Nm^3 to 20 mg/Nm^3, an additional ESP would be required. 100 mg/Nm^3 is an expert estimate by TNO valid for the majority of non-EU(25) countries. In addition, a fabric filter must be added to control fugitive emission and furthermore various suction hoods have to be installed. Based on an average of the above mentioned cost data, we have derived the following specific investment and operational costs for both these measures to be taken:

Investment costs € 24 (1996) / tonne production capacity (in tonnes/year)
Operational costs € 2.7 (1996)/ tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for non-EU(25)+ countries since it is expected that the more stringent proposal for a revised Protocol ELV will be met as a result of the implementation of the IPPC Directive.

3.6 Electric arc furnaces

Release of PM by electric arc furnaces primarily takes place in two ways, primary waste gas from the furnace and secondly, fugitive emission from tapping. The technique to control PM emission from direct waste gasses that is considered BAT, is a well designed fabric filter (controlling both the primary and secondary emission) (Rentz et al., 2004a). Thus concentrations below 15 mg/m^3 can be reached (Rentz et al., 2004a, Entec, 2001). Fugitive emission can be effectively abated by for instance closing the melt shop roof or enclosement by a 'dog house', increase the gas extraction rate and install additional fabric filters.

IFARE specifies abatement costs using fabric filters to control the primary waste gas stream to be US$24/tonne capacity (operational costs to be estimated by taking 10% of the investment cost for a fabric filter). The capital cost for abating fugitive emission would be M€ 10 to 17 and the operating costs would be € 0.8/tonne (2000) (Entec, 2001). We can assume the average large EAF to have a capacity of 100,000 – 800,000 (500,000 average) tonnes/year

In order to achieve a reduction of PM concentration in furnace off-gasses from 20 to 10 – 15 mg/Nm^3, an additional fabric filter would be needed. Capturing and collecting fugitive dust would require a fabric filter and various suction hoods. Based on an average of the above mentioned cost data, we have derived the following specific investment and operational costs for controlling both primary and secondary releases:

Investment costs € 50 / tonne production capacity (in tonnes/year)
Operational costs € 2 / tonne production capacity (in tonnes/year) · year^{-1}

It is expected that after the implementation of the IPPC Directive in the EU(25)+, the majority of the electric arc furnaces will not achieve 15 mg/Nm^3. Therefore, costs are calculated for all countries. It should be remarked that in the year 2000 however, there were already several individual plants in Europe that achieved a PM emission below 15 mg/Nm^3. For these single cases costs are overestimated.

3.7 Primary Copper Production

Primary copper is produced using various process types (Outokumpu, Mitsubishi, Noranda etc.). Electrolytic refining of copper and the production and refining of secondary copper is not considered here. For all existing process types/steps to produce primary copper, PM emissions below 5 mg/m^3 from the main emission points can be achieved by adding modern high performance fabric filters (besides the regular control technologies), after waste gas cooling (Rentz et al., 2004a, Entec, 2001). In case the characteristics of the collected dust hamper the use of fabric filters, wet ESP or ceramic filters are an alternative. After these control measures have been taken, fugitive emission would be more important than the residual stack emission (Rentz et al., 2004a, Entec 2001). BAT also entails effective capturing and cleaning of fugitive releases. (Rentz et al., 2004a) lists installed costs for the application of bag house fabric filters in the production of primary copper.

- M€ 20 for a 750,000 Nm^3/h gas flow shaft furnace, converter and anode furnace
- M€ 14 for a top blown rotary converter (730,000 Nm^3/h, excluding ducting and stack)
- M€ 2 – 2.5 MEuro for a 70,000 Nm^3/h fabric filter.

(Entec., 2001) presents capital and operating costs for the application of additional bag houses to various primary copper production types/steps. Specific investment costs range from € 20 to 80/Nm^3 with total investments of M€ 10 – 20 per plant. Operating costs are estimated to be an additional 10% of the capital costs for this types of measures. We assume an average annual capacity of 80,000 tonnes annually per plant.

In order to reduce stack concentrations from 10 – 20 mg/Nm^3 to 5 mg/Nm^3, an additional high performance fabric filter would be required. Based on an average of the above mentioned cost data, we have derived the following specific investment and operational costs relations:

Investment costs € 250 / tonne production capacity (in tonnes/year)
Operational costs € 25 / tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for all countries since it is expected that (based on Phase I data) the more stringent proposal for a revised Protocol ELV (5 mg/Nm^3) will not be entirely met as a result of the implementation of the IPPC Directive (which would come down to about 10 – 20 mg/Nm^3). It should be remarked though that in the year 2000 there were individual plants in Europe (e.g. Germany) that already achieved an emission below 5 mg/Nm^3. For these cases costs are unfortunately over-estimated.

3.8 Primary Zinc Production

Primary zinc is produced by either an electrochemical or a pyrometallurgical process. Regarding air emission of HM, for both processes the roasting and casting steps are relevant as well as for the thermal process the smelting step (Entec, 2001). When not followed by a sulphur removal plant, a high performance fabric filter with burst detection after gas cooling is considered BAT. BAT would enable concentrations below 5 mg/Nm^3. Alternatives are a venturi scrubber or a wet ESP in case a sulphuric acid plant follows (Rentz et al., 2004a). With BAT to control stack emission, fugitive emission would be the most relevant remaining emission source (Entec, 2001). Entec (2001) refers to the data available for the production of copper for an indication of abatement costs. Capital costs of M€ 33 are estimated for achieving additional emission reduction in order to meet tighter future emission standards, for a 200,000 tonnes/year smelter that uses the thermal process.

Based on the above mentioned cost data to add a high performance fabric filter capable of achieving 5 mg/Nm^3, we have derived the following specific investment and operational costs relations:

Investment costs € 165 / tonne production capacity (in tonnes/year)
Operational costs € 17 / tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for all countries since it is expected that (based on Phase I data) the more stringent proposal for a revised Protocol ELV (5 mg/Nm^3) will not be entirely met as a result of the implementation of the IPPC Directive (which would come down to about 10 – 20 mg/Nm^3). Iin the year 2000 there were individual plants in Europe (e.g. in Germany) that achieved already emission below 5 mg/Nm^3. For these cases costs are overestimated.

3.9 Primary Nickel Production

According to (Entec, 2001) very low residual emission of particles can be achieved using high performance fabric filters. With BAT to control stack emission, fugitive emission would in a relative sense become more important (Entec, 2001).

Entec (2001) refers to the cost data available for the production of copper as an indicative guide for abatement costs for nickel production. Entec estimates a capital cost of M€ 10 for a 3-field ESP to reduce process emissions from a 41,000 tonne/year smelter. It is uncertain whether this measure would result in concentrations below 5 mg/Nm^3. We will assume it will, however if proven not, an additional fabric filter would be needed and abatement costs would be significantly higher.

Based on the Entec cost data, we have derived the following specific costs:

Investment costs € 244 / tonne production capacity (in tonnes/year)
Operational costs € 24 / tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for all countries since it is expected that (based on Phase I data) the more stringent proposal for a revised Protocol ELV (5 mg/Nm^3) will not be entirely met as a result of the implementation of the IPPC Directive (which would come down to about 10 – 20 mg/Nm^3). In the year 2000 there were individual plants in Europe (e.g. Finland) that achieved already emission below 5 mg/Nm^3. For these cases costs are overestimated.

3.10 Primary Lead Production

Primary lead is produced by a number of pyrometallurgical processes. According to (Entec, 2001) very low residual emission of particles can be achieved using high performance fabric filters. After implementation of BAT to control stack emission, fugitive emission would be the most relevant remaining emission source (Rentz et al., 2004a, Entec, 2001).

There is little cost information available for primary lead production. When regarding costs of high performance fabric filters in other non-ferrous metals sectors we can estimate total capital costs to be around M€ 10 for an average production capacity of 60,000 tonnes annually and a 200,000 Nm^3/h gas flow.

Investment costs € 166 / tonne production capacity (in tonnes/year)
Operational costs € 16 / tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for country groups 1, 2 and 3 since it is expected that (based on Phase I data) the more stringent proposal for a revised Protocol ELV (5 mg/Nm^3) will not be entirely met as a result of the implementation of the IPPC Directive (which would come down to about 10 mg/Nm^3). In the year 2000 there were individual plants in Europe that did achieve emission below 5 mg/Nm^3. For these few cases costs are overestimated.

3.11 Coal-fired Power Plants

Regardless of the HM Protocol, all coal-fired power stations in Europe are assumed to be equipped with at least a conventional ESP in 2020 (Berdowski et al., 1998). The application of a high performance ESP or an additional fabric filter is regarded BAT for controlling PM. Both techniques have the potential to reduce dust emission to stack concentrations below 20 mg/Nm^3 (Rentz et al., 2004a). Combustion plants equipped with a conventional 2 or 3-field ESP and that have emissions of around 50 mg/Nm^3, could be retrofitted with an additional fabric filter or ESP to achieve 20 mg/m^3. When coal-fired plants are equipped with FGD, 20 mg/Nm^3 will be achieved without any further measures (Rentz et al., 2004a).

Specific capital costs of a regular ESP are estimated to be between 5 and 15 Euro per m^3/h for large (>200,000 m^3/h) gas flow rates (Rentz et al., 2004a, Berdowski et al., 1998). Operational costs are about US$ 0.2/MWh·year. According to IFARE, the investment cost of a fabric filter is approximately 30% higher than that of an ESP. IFARE estimates capital costs to be US$28.9/MWh (1991) and running costs US$ 5.8/MWh·year^{-1} (1991).

Further control of Hg emission is possible by means of activated carbon injection before the fabric filter. Reported costs would be US$ 34.6/MWh (capital, corrected IFARE data) and US$ 8.1/MWh·year^{-1} (operational, corrected IFARE data) (Rentz et al., 2004a).

Based on the cost data presented above, we have derived the following specific costs for advanced PM emission control (average assumed capacities of 600 MWel):

Investment costs € 2.7 / GJ fuel (per year)
Operational costs € 0.53 / GJ fuel (per year) · year^{-1}

Removing Hg from the flue gasses would lead to the following additional specific costs:

Investment costs € 3.3 / GJ fuel (per year)
Operational costs € 0.74 / GJ fuel (per year) · year^{-1}

It is expected that as a result of implementation of both the IPPC and the 2nd Sulphur Protocol, additional measures as a result of the more stringent proposal for a revised Protocol ELV are only needed for country group 3. Therefore, the cost calculations are only made for country group 3 (see Table 6). Specific Hg removal techniques are not expected to be implemented anywhere in Europe and thus an assessment of abatement costs is made for all countries.

3.12 Oil-fired Power Plants

In order to meet an emission standard of 20 mg/Nm^3 (or even 50 mg/Nm^3) oil-fired boilers must be fitted with ESP. Reported removal efficiencies are around 80% in that case. With FGD, concentrations below 25 mg/m^3 should be achieved. For heavy oil-fired power plants with high load factors, FGD would have to be installed on the longer term as a result of the 2nd Sulphur Protocol. The majority of heavy oil is however used in plants with lower load factors.

Refinery boilers burning heavy fuel oil can be fitted with ESP resulting in a capital cost of M€ 6 and an operating cost of M€ 0.2/year for a gas flow rate of 5 billion m^3/year (Entec., 2001). Replacement of heavy fuel oil with natural gas results in an additional € 10 /tonne oil (Entec., 2001). IFARE reports costs of ESP only to be US$ 1.6/MWh (1991) capital and US$ 0.2/MWh · year^{-1} (1991) operational.

We have derived the following specific costs for ESP retrofit, based on the information given above:

Investment costs € 0.26 / TJ fuel (per year)
Operational costs € 0.03 / TJ fuel (per year) · year^{-1}

It is not expected that the implementation of the IPPC Directive or the 2nd Sulphur Protocol will result in all heavy oil-fired combustion plants >50MWth being outfitted with an ESP or FGD because of the high cost and relatively small PM emission reduction. Moreover, sulphur contents are expected to decline in the future, decreasing the necessity of both ESPs or FGD units. Costs of ESP are therefore estimated for all countries.

3.13 Cement Production

According to (Rentz et al., 2004) the main source of metal-laden dusts in the production of cement is the kiln system (preheaters, precalciners, rotary kilns and clinker coolers). This also holds true for mercury release. Besides good process practice to minimize fugitive emission, efficient PM control by the application of electrostatic filters (ESP) and fabric filters is considered BAT, and concentrations below 15 mg/Nm^3 are achievable.

(Rentz et al., 2004a) states that the majority of the process input of Hg comes from the raw materials rather than the fuels. This reduces the possibilities for primary Hg control measures such as fuel selection. IFARE draws a parallel with coal-fired utility boilers with respect to the possibilities for Hg removal (US$ 34.6/MWh capital cost and US$ 8.1/MWh·year^{-1} operational costs for activated carbon injection, corrected data).

(Rentz et al., 2004a) presents PM emission abatement costs for 3,000 tonnes clinker/day cement plant.

- Rotary kiln, M€ 2.1 – 4.3 investment, € 0.15 – 0.35/tonne operational costs
- Clinker coolers, M€ 1 – 1.4 investment, € 0.1 – 0.15/tonne operational costs
- Cement mills, M€ 0.3 – 0.5 investment, € 0.03 – 0.04 /tonne operational costs

Total costs when summed are M€ 3.4 – 6.2 investments and € 0.28 – 0.54/tonne operational costs. The application of ESP is an alternative technique with costs resembling those of fabric filters. Entec (2001) reports capital costs of particulate matter emission control in the cement industry using fabric filters to range from 1 to M€ 4. Operational cost varies from € 0.1 to 0.3/tonne clinker (Entec, 2001).

Based on an evaluation of the available cost data, the following cost relation has been derived:

Investment costs € 4.5 / tonne production capacity (in tonnes/year)
Operational costs € 0.4 / tonne production capacity (in tonnes/year) · year^{-1}

These costs will be calculated for country groups 2 and 3 because the new revised ELV would be met anyway in the EU(25+) as a result of the IPPC Directive and the EU Waste Directive.

On the basis of the cost information available for power plants, a rough additional estimate of the costs for Hg removal has been made based on a specific waste gas production of 4,000 Nm^3/tonne cement:

Investment costs € 20 / tonne production capacity (in tonnes/year)
Operational costs € 5 / tonne production capacity (in tonnes/year) · year^{-1}

Hg removal is not regarded as a part of the IPPC BAT. Costs of Hg emission control are therefore calculated for all countries .

3.14 Glass production

This sector covers the manufacture of container glass, flat glass, special glass and crystal glass. The production of crystal glass can give rise to significant emission of Pb while the production of other glass types is an important source of Se. Both these metals are for the larger part particle-bound. BAT for glass furnaces (both electrically and gas-heated) is a fabric filter or ESP (Rentz et al., 2004a). With both techniques PM stack concentrations below 30 mg/Nm^3 are achievable.

IFARE reports the abatement costs to range from M€ 0.5 to 2.75 (capital) and from M€ 0.037 to 0.186/year (operational) for an average large production plant.

We would estimate the capacity of such an average plant at 150000 tonnes/ year. Specific costs then are:

Investment costs € 11 / tonne production capacity (in tonnes/year)
Operational costs € 0.74 / tonne production capacity (in tonnes/year) · year^{-1}

Costs are calculated for the non-EU(25)+ since it is expected that the more stringent proposal for a revised Protocol ELV will be met as a result of the implementation of the IPPC Directive.

3.15 Coke ovens

Coke ovens have been identified as a relevant source of trace metals in Phase I of this study (Denier van der Gon et al., 2005). Heavy metal emission could be the result of the combustion of coke oven gas that could potentially contain trace metals. However, coke oven gas is not likely to contain high amounts of metals since solid or condensable matter is usually removed before the gas is used as a fuel.
Besides combustion emission, fugitive emission from oven charging, door leakage and coke pushing, cooling, quenching and grinding could give rise to heavy metal emission.

Cost data for emission control measures for coke ovens is scarce. In (Berdowski et al., 1997) investment costs for highly sealing oven doors are given. € 2.1/ tonne (1996) coking capacity is reported. For controlling other fugitive emission a rough cost estimate could be made based on the data available for other fugitive emission sources such as electric arc furnaces. Measures would involve the construction of suction hoods connected to ESPs, to all individual ovens. Capital costs are expected to be high, at least as high as the upper value of the range reported for electric arc furnaces (M€ 20 (1996) investment and € 4/tonne (1996) operational). The average capacity of a larger coking plant is something like 2 Mtonnes.

The following specific costs are thus estimated:

Investment costs € 13 / tonne production capacity (in tonnes/year)
Operational costs € 4 / tonne production capacity (in tonnes/year) · year^{-1}

This estimate must be regarded as no more than a first order approximation.

Costs are calculated for country group 2 and 3 since it is expected that the more stringent proposal for a revised Protocol ELV will be met as a result of the implementation of the IPPC Directive and the UN/ECE POP Protocol.

3.16 Lead content of gasoline in UNECE-Europe

The UNECE HM Protocol requires that no later than 6 months after the date of entry intro force of this Protocol, the lead content of marketed petrol shall not exceed 0.013 g/l. Under special conditions this time may be extended to a period of up to 10 years, during which a Party may market leaded petrol with a lead content not exceeding 0.15 g/l. Our assumption is that in 2020 full implementation of the HM Protocol implies all marketed petrol in the UNECE shall not exceed 0.013 g/l. However autonomous measures in the European Community are going beyond this limit value. In the European Community the marketing of leaded petrol is banned since 1 January 2000 according to Directive 98/70/EC (EC, 1998). The specifications for petrol and diesel sold in the European Community are included in Directive 98/70/EC. The maximum content of lead in unleaded petrol is 0.005 g/l. Hence for countries belonging to the EU(25)+ all marketed petrol in 2020 shall not exceed 0.005 g/l.

3.16.1 Proposed additional measure and costs.

The proposed additional measure to reduce lead emissions from road transport is a further tightening of the lead content of marketed petrol in a future HM Protocol from 0.013 g/l to 0.005 g/l (see also Table 11). This implies all EU countries already comply with the 0.005 g/l and additional reduction is achieved in non-EU countries. We presently assume that the additional costs are negligible. It appears that the higher limit value of 0.013 g/l is maintained to rule out contamination problems in countries where leaded gasoline is marketed at the same time. For example, if unleaded gasoline is transported in a tanker that was previously used for leaded gasoline the lead content of the gasoline will slightly increase due to remixing and contamination with traces of leaded fuel. All countries that no longer market leaded gasoline appear to comply with the 0.005 g/l limit value at no additional costs (EU, 2004a)

3.16.2 The impact of further tightening the lead content of unleaded gasoline

The exact lead content of unleaded fuel is usually not given, only that the unleaded fuel meets the EC and/or UNECE HM Protocol limit value of 0.005 or 0.013 g/l, respectively. The annual fuel quality monitoring reports produced for DG Environment are based on country submissions under Directive 98/70/EC1 and summarising the quality of petrol and diesel in the community for the years 2001-2003. (EU 2003, 2004a 2004b). The 10 new Member States will first have to submit reports to cover the 2004 monitoring year and are therefore not covered in the presently publicly available reports. Since the exact lead contents are not specified for countries that do not officially report lead emissions from road transport we have applied the limit value as the default concentration. However, in reality it is very possible that the actual lead content is considerably smaller. We have investigated this hypothesis through a screening of the EU-Fuel Quality Monitoring reports. The annual fuel quality monitoring (EU 2003; 2004a; 2004b) shows that all EU countries comply with the EU limit value of < 0.005 g Pb /l. For most countries the limit of detection for lead is equal to, or just below, the EU limit value of 0.005 g/l, for example: 0.002 g/l (Netherlands), 0.003g/l (Sweden), 0.005 g/l (Germany, Italy) (EU, 2004a,b) and values reported as 0 in the FQM Tables will fall into the range “0-detection limit”. These countries therefore comply with the EC limit value and more detailed analysis is officially not required. To get an estimate of the actual lead content we screened the EC fuel quality reporting for countries that report analysis with a lower detection limit than 0.005 g/l (Table 12). The data reported in Table 12 indicate that the average real-world Pb content in unleaded fuel is currently ~ 0.001 g/l and over time may further decrease to ~ 0.0004 as the potential contamination with (traces of) leaded fuel due to transport and handling is becoming less plausible. Hence applying the default lead content of 0.005 g/l approximately overestimates lead emissions by a factor of ~ 5. It should be stressed that this is our default value, the structure of the emission inventory is such that whenever available official country emission data have been used (Denier van der Gon et al., 2005). It is interesting to note that Table 12 suggests that a best guess concentration value of 0.001 g/l would still result in considerable Pb emission due to the large quantities of petrol consumed. Countries officially reporting zero lead emission from road transport may possibly underestimate real-world emissions.

The measure proposed to further reduce Pb emission from road transport is to further tighten the UNECE limit value of Pb in gasoline from 0.013 g/l to 0.005 g/l. It is possible that this limit value is already met in (some of) the non-EU(25)+ countries but, as indicated earlier, actual exact Pb content of fuels is not reported. Our best guess is that the actual lead content of unleaded petrol will be 0.001 g/l (Table 12), a factor 5 below the limit value. To calculate the potential for emission reduction the remaining emission in 2020 has been calculated using the national petrol consumption and assuming a Pb content of 0.001 g/l. The difference between the emissions from unleaded petrol in 2020 assuming full implementation of the HM Protocol and the newly calculated emission level is the emission reduction potential. Again, this may be a partly virtual emission reduction potential but data to ascertain this are lacking. This may vary by country depending on the origin of the 2020 FIHM data (official emission data versus default calculation using 0.013 g Pb/l)

Table 12 Pb content (g/l) of unleaded petrol min. RON=95 (EU limit value < 0.005 g/l).

Country	Number of samples	Min	Max	Mean	Reference
Finland	98		0.0007	0.0004	EU, 2004a
	99			0.0004	EU, 2004b
France	9	0	0.0012	0.001	EU, 2003
	30		0.005	0.0012	EU, 2004a
Greece	82	0.001	0.004	0.002	EU, 2004a
	85	0.001	0.004	0.002	EU, 2004b
Ireland	80	0	0.001	0.00004	EU, 2004b
Italy	221	0.001	0.002	0.0015	EU, 2003
Spain	204	0	0.004	0.001	EU, 2003
	267	0	0.003	0.001	EU, 2004a
Sweden	739	0.001	0.005	0.001	EU, 2003
UK	1362	0	0.004	0.001	EU, 2003
Average		0.0004	0.003	0.001	

3.17 Summary of selected measures

In this chapter the measures that may be implemented to reach the proposed ELVs of a revised HM Protocol have been discussed for each major source category. The selected measures are summarized for Package 1 and Package 2 in Table 13 and Table 14, respectively. The costs associated with implementation of these measures and the emission reduction achieved upon complying with the ELVs shown in Table 13 and Table 14 are the basis for the calculations and results discussed in the next chapter.

Table 13 Overview of selected measures and emission limit values Package 1.

Source Category	Fuel	Proposed limit value	Applied measure Package 1
Heat / Power Plants	Solid fuels	20 mg/m^3 (PM, all plants >50 MWth)	Addition of fabric filters to coal-fired large combustion plants, ELV = 20 $mgPM/Nm^3$
	Liquid fuels	20 mg/m^3 (PM, all plants >50 MWth)	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20 $mgPM/Nm^3$
Industrial Combustion	Solid fuels	20 mg/m^3 (PM, all plants >50 MWth)	Addition of fabric filters to coal-fired large combustion plants, ELV = 20 $mgPM/Nm^3$
	Liquid fuels	20 mg/m^3 (PM, all plants >50 MWth)	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20 $mgPM/Nm^3$
Coke Ovens		50 mg/m^3 (PM in COG); limit fugitive releases	Control of fugitive emission from coke ovens by capturing and filtering, ELV = 50 mg PM/Nm^3
Iron & Steel, Blast furnaces		10 mg/m^3 (PM, BFG); 20 mg/m^3 (PM, Casting bay evacuation)	Addition of a fabric filter and evacuation to control fugitive emission from blast furnaces, ELV = 20 $mgPM/Nm^3$
Iron & Steel, Sinter Production		20 mg/m^3 (PM)	Addition of fabric filters to sinter plant stacks, ELV = 20 $mgPM/Nm^3$
Iron & Steel, Electric Arc Furnace		15 mg/m^3 (PM)	Addition of fabric filters to control primary and secondary emission from electric arc furnaces, ELV = 15 $mgPM/Nm^3$
Primary Copper Production		5 mg/m^3 (PM)	Addition of fabric filters, wet ESP or ceramic filters to control stack emission from primary Cu smelters, ELV = 5 $mgPM/Nm^3$
Primary Zinc Production		5 mg/m^3 (PM)	Addition of fabric filters, scrubbers or ESP to control stack emission from primary Zn smelters, ELV = 5 $mgPM/Nm^3$
Primary Nickel Production		5 mg/m^3 (PM)	Addition of fabric filters to control stack emission from primary Ni smelters, ELV = 5 $mgPM/Nm^3$
Chlorine Production [a]		-0.5 g/Mg Cl2 (Hg)	Reduction of Hg emission in Hg-based process, ELV = 0.5gHg/tonneCl2
Cement Production		30 mg/m^3 (PM); 0.05 mg/m^3 (Hg)	Application of high performance ESP or FF to control primary emission from cement kilns
Glass Production		30 mg/m^3 (PM)	Application of fabric filters or electrostatic precipitators in glass production, ELV = 30 $mgPM/Nm^3$
Road Transport (Exhaust)	Gasoline	5 mg/l (Pb)	Lowering the maximum allowable lead content of unleaded gasoline from 13 to 5 mg/l (assumed effective concentration 1 mg/l)
Medical Waste Incineration [a]		10 0r 25 mg/m^3 (PM), 0.03 mg/m^3 (Hg)	Prededusting with ESP, lime and activated carbon injection followed by FF to control Hg emission from medical waste incin., ELV = 0.05 $mgHg/Nm^3$
Iron & Steel, Oxygen Furnace [b]		20 mg/m^3 (PM)	Addition of dry ESP or scrubber to control BOF primary emission, additional control of fugitive emission by fabric filters, ELV = 20 $mgPM/Nm^3$
Primary Lead Production [b]		5 mg/m^3 (PM)	Addition of fabric filters to control stack emission from primary Pb smelters, ELV = 5 $mgPM/Nm^3$

a) Source scheduled for evaluation by the 1998 UNECE Protocol on Heavy Metals.

b) Source included due to uncertainty in source strength of Pb from road transport.

Table 14 Overview of selected measures and emission limit values Package 2.

Source Category	Fuel	Proposed limit value	Applied measure Package 2
Heat / Power Plants	Solid fuels	Not applicable	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% removal efficiency
	Liquid fuels	Not applicable	Fuel switch from heavy fuel oil to natural gas
Industrial Combustion	Solid fuels	Not applicable	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% removal efficiency.
	Liquid fuels	Not applicable	Fuel switch from heavy fuel oil to natural gas
Cement Production	-	0.05 mg/m^3 (Hg)	Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05 mg Hg/Nm^3

4. Results and Discussion

The cost and emission reduction of a set of revised emission limit values (ELVs) for heavy metals and particulate matter have been estimated by source category. The results for each individual country are presented in Annex 2 (that can be found on the CD-ROM included in this report). The results are discussed in this chapter on an aggregated level by summing the remaining emissions, emission reductions, and associated costs for two country groups (Table 15). Since we assume full implementation of the HM Protocol by all countries in 2020, the major discrepancy between countries is the foreseen (mandatory) autonomous developments. Therefore, the split between countries is limited to two country groups. Especially the obligation of the EU(25)+ countries to implement the IPPC Directive is important in assessing the effort needed to meet the revised ELVs of a revised HM Protocol. In addition, the potential for further emission reduction is limited in case a sector or country already complies with IPPC. This justifies the split in these two country groups.

Table 15 Country groups, number of countries in group and country group code

Description	Nr. of countries	Group Code
All countries that have to implement EC Directives (EU(25), NOR, CHE)	27	EU(25)+
No implementation of EC Directives	17	non-EU(25)+

4.1 Emission reduction and associated costs upon revision of the HM Protocol

The emission reduction and associated costs of a revision of the HM Protocol are summarized for the EU(25)+ and non-EU(25)+ in Table 16 and Table 17, respectively. The tables list the sectors that have been singled out as suitable candidate sectors for possible revision according to the methodology described in section 2.4. Since the considered autonomous measures differ between the two country groups, a different array of sectors is listed in Table 16 and Table 17. The specific measures identified as necessary to meet the revised ELVs, are listed in the 13th and 24th column of Table 16 and Table 17. For an explanation of the abbreviations used to describe the selected measures we refer to the first Table of Annex 2. The total annual cost (in M€) for each listed measure is calculated as the annuity of the investment costs plus the annual operational costs. The emission reduction (in tonnes) after implementation of Package 1 measures is presented for the three priority heavy metals (Cd, Hg and Pb) and 6 others (As, Cr, Cu, Ni, Se and Zn) in the 15th to 23rd column. The costs and achieved emission reduction of a revised HM Protocol has been estimated for each individual European UNECE Member State. The results on

a country basis are presented in Annex 2 (available on CD-ROM) and are not further commented in this report.
A second set of measures has been evaluated which we refer to as "Package 2". Package 2 focuses specifically on the control of Hg emission. In general, measures under the HM Protocol focus on dust removal, thereby reducing the emissions of HM. For Hg this is less efficient as most of the Hg emissions occur in the gaseous phase. End-of-pipe removal of Hg is in most cases not regarded as Best Available Technology (BAT) by IPPC, and costs are usually relatively high.
The last block of data in Table 16 and Table 17 lists the costs of Package 2 measures and the emission reduction due to implementation (see Annex 2 for abbreviations). As an example we will discuss Hg emissions; from Heat/Power Plants firing Brown Coal in the EU(25)+ (first data row, Table 16). Under Package 1 no revision is foreseen for this source, hence the remaining emission would be 12.83 tonnes Hg/yr and the emission reduction due to Package 1 revision is 0 kg hg/yr. Package 2 proposes to reduce emissions from this source by implementing measure S2-2 (Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon with an assumed 80% removal efficiency). The emission reduction due to this measure is 10.26 tonnes Hg/year (first data row, Table 16). The emission after this measure (not shown in Table 16) is therefore 12.83 minus 10.26 = 2.57 tonnes Hg/year.

Interpretation of Table 16 and Table 17 for a source where both a Package 1 measure and Package 2 measure are possible, appears more complicated but is in fact rather straightforward. As an example we will discuss industrial combustion using heavy fuel oil in the EU(25)+ (Table 16, 10th data row). The costs of measure S1-1 for this source category in this country group is M€ 14, the Cd emission and the reduction due to Package 1 Protocol revision for this source is 3.93 and remaining emission is 7.18 minus 3.93 = 3.25 tonnes Cd/year. The costs of the HM Protocol revision following the Package 2 measure S2-1 is M€ 71 and the emission reduction for Cd is 7.18 tonnes/year. Hence the emission reduction after Package 2 is (7.18 - 7.18 =) 0 tonnes/year. It should be noted that if for a particular source a Package 2 measure is selected, the Package 1 measure for this source category will not be implemented and the costs associated with this Package 1 measure will not be made. It is important to realize that Package 1 and Package 2 measures are not to be implemented sub-sequentially but a choice has to be made for a Package 1 or a Package 2 measure.

It is important to realize that if Package 2 is implemented only a few measures of Package 1 become redundant. For example, a fuel switch in refineries from heavy fuel oil to gas makes additional dust removal no longer necessary. However, to realize the full reduction potential of Package 1 and 2 almost all costs listed in the individual Package 1 and 2 Tables need to be made. The emission reduction due to a possible revision of the HM Protocol involving both Package 1 and 2 is presented in section 4.3. The results summarized in Table 16 and Table 17 will be briefly discussed for the individual sectors in the next sections.

Table 16 Emission in 2020 after full implementation of the HM Protocol and emission reduction after a possible revision of the HM Protocol, associated emission reduction and costs for the EU(25)+ for Package 1 and Package 2, respectively.

			Emission 2020 FI existing HM Protocol (tonnes)								
Sector	Detailed Sub-Sector	Detailed Fuel	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	7.42	1.03	4.62	3.58	12.83	6.10	7.99		23.11
1_PHP	Heat / Power Plants	Hard Coal	16.48	1.09	11.15	18.35	28.66	23.16	51.51	19.35	228.17
1_PHP	Heat / Power Plants	Heavy Fuel Oil	3.03	2.72	11.56	5.17	0.86	118.41	6.26	2.84	1.40
1_PHP	Heat / Power Plants	Peat	0.44	0.05	0.38	0.63	0.68	0.27	0.55		0.87
1_PHP	*Other emission from Heat/Power Plants*		*0.32*	*1.37*	*0.59*	*1.35*	*0.32*	*3.12*	*6.63*	*0.07*	*341.06*
2_RCO	*Residential, commercial and other combustion*		*17.66*	*17.38*	*30.29*	*55.11*	*5.72*	*90.76*	*108.77*	*2.37*	*398.27*
3_IND	Cement Production	-	5.87	2.38	9.16		57.08	15.22	27.66	0.59	66.53
3_IND	Chlorine Production	-					0.01				
3_IND	Industrial Combustion	Brown Coal	0.07	0.01	0.05	0.02	0.20	0.05	0.02		0.10
3_IND	Industrial Combustion	Hard Coal	2.45	0.13	3.57	1.81	4.10	8.23	5.96	1.19	20.11
3_IND	Industrial Combustion	Heavy Fuel Oil	7.18	3.37	18.78	4.02	0.93	151.68	6.24	3.41	2.47
3_IND	Industrial Combustion	Peat	0.04	0.00	0.00	0.00	0.02	0.01	0.00		0.01
3_IND	Iron & Steel, Electric Arc Furnace	-	7.46	17.84	27.51	33.53	0.18	1.96	99.48	5.73	1459.63
3_IND	Iron & Steel, Sinter Production	-	4.58	6.68	29.64	42.45	1.68	50.31	359.00	1.66	83.19
3_IND	Oil Refineries	Hard Coal	0.33	0.00	0.63	0.07	0.45	0.66	0.26	0.14	1.36
3_IND	Oil Refineries	Heavy Fuel Oil	6.53	2.45	15.99	2.98	0.59	110.12	4.17	2.40	0.96
3_IND	Primary Copper Production	-	8.68	3.40		70.81	0.19		11.83		128.07
3_IND	Primary Lead Production	-	0.88	0.77		3.07	2.28		145.03		21.68
3_IND	Primary Nickel Production	-			86.16			41.03			
3_IND	Primary Zinc Production	-		3.06			0.55		11.46		373.11
3_IND	*Other emission in Industry*		*72.79*	*19.31*	*118.25*	*180.07*	*8.28*	*193.85*	*838.63*	*110.09*	*3470.31*
4_SPU	*Emission from Solvent Use*			*0.00*			*0.04*		*0.02*		
5_ROT	Road Transport (Exhaust)	-							844.19		
5_ROT	*Other Road Transport emission*		*0.37*	*7.50*	*23.46*	*472.61*	*0.07*	*45.85*		*3.16*	*1366.37*
6_NRT	*Non-Road Transport*		*0.68*	*0.21*	*0.89*	*179.38*	*0.26*	*35.71*	*6.50*	*1.20*	*12.55*
7_WAS	Clinical Waste Incineration	-	0.00	0.12	0.05	0.07	0.20	0.02	2.77	0.00	1.28
7_WAS	*Other emission from Waste Generation and Disposal*		*1.72*	*4.40*	*22.57*	*31.78*	*14.99*	*7.87*	*77.01*	*0.62*	*614.58*
8_AGR	*Emission from Agriculture*		*0.03*	*0.03*	*0.03*	*0.07*	*0.02*		*0.07*		
	Total sectors listed above		165	95	415	1107	141	904	2622	155	8615

					Emission reduction Package 1 measures (tonnes)								
Sector	Detailed Sub-Sector	Detailed Fuel	Package 1 measure	Package 1 costs (M€)	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal											
1_PHP	Heat / Power Plants	Hard Coal											
1_PHP	Heat / Power Plants	Heavy Fuel Oil	S1-1	16	1.66	1.50	8.67	3.36	0.05	72.82	3.44	1.35	0.79
1_PHP	Heat / Power Plants	Peat											
1_PHP	*Other emission from Heat/Power Plants*												
2_RCO	*Residential, commercial and other combustion*												
3_IND	Cement Production	-											
3_IND	Chlorine Production	-	S1-10	0					0.01				
3_IND	Industrial Combustion	Brown Coal											
3_IND	Industrial Combustion	Hard Coal											
3_IND	Industrial Combustion	Heavy Fuel Oil	S1-1	14	3.93	1.86	14.09	2.61	0.05	93.28	3.43	1.62	1.39
3_IND	Industrial Combustion	Peat											
3_IND	Iron & Steel, Electric Arc Furnace	-	S1-3	704	1.08	2.59	11.53	8.06	0.00	0.54	14.45	0.74	219.11
3_IND	Iron & Steel, Sinter Production	-	S1-13	350	1.73	2.54	18.08	19.74	0.06	24.35	136.42	0.55	32.11
3_IND	Oil Refineries	Hard Coal											
3_IND	Oil Refineries	Heavy Fuel Oil	S1-1	10	3.57	1.35	11.99	1.94	0.03	67.72	2.29	1.14	0.54
3_IND	Primary Copper Production	-	S1-4	133	4.46	1.76		43.74	0.01		6.11		67.45
3_IND	Primary Lead Production	-	S1-16	43	0.44	0.38		1.87	0.11		72.52		11.16
3_IND	Primary Nickel Production	-	S1-5	14			74.58			32.44			
3_IND	Primary Zinc Production	-	S1-16	59		2.29			0.04		8.60		282.63
3_IND	*Other emission in Industry*												
4_SPU	*Emission from Solvent Use*												
5_ROT	Road Transport (Exhaust)	-	S1-7								827.11		
5_ROT	*Other Road Transport emission*												
6_NRT	*Non-Road Transport*												
7_WAS	Clinical Waste Incineration	-	S1-8	1					0.08				
7_WAS	*Other emission from Waste Generation and Disposal*												
8_AGR	*Emission from Agriculture*												
	Total sectors listed above			1344	17	14	139	81	0	291	1074	5	615

					Emission reduction Package 2 measures (tonnes)								
Sector	Detailed Sub-Sector	Detailed Fuel	Package 2 measure	Package 2 costs (M€)	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	S2-2	2748					10.26				
1_PHP	Heat / Power Plants	Hard Coal	S2-2	5136					22.92				
1_PHP	Heat / Power Plants	Heavy Fuel Oil	S2-1	79	3.03	2.72	11.56	5.17	0.86	118.41	6.26	2.84	1.40
1_PHP	Heat / Power Plants	Peat	S2-2	185					0.55				
1_PHP	*Other emission from Heat/Power Plants*												
2_RCO	*Residential, commercial and other combustion*												
3_IND	Cement Production	-	S2-3	1652					11.42				
3_IND	Chlorine Production	-	S2-4	0					0.01				
3_IND	Industrial Combustion	Brown Coal	S2-2	45					0.16				
3_IND	Industrial Combustion	Hard Coal	S2-2	554					3.28				
3_IND	Industrial Combustion	Heavy Fuel Oil	S2-1	71	7.18	3.37	18.78	4.02	0.93	151.68	6.24	3.41	2.47
3_IND	Industrial Combustion	Peat	S2-2	9					0.01				
3_IND	Iron & Steel, Electric Arc Furnace	-											
3_IND	Iron & Steel, Sinter Production	-											
3_IND	Oil Refineries	Hard Coal	S2-2	101					0.36				
3_IND	Oil Refineries	Heavy Fuel Oil	S2-1	51	6.53	2.45	15.99	2.98	0.59	110.12	4.17	2.40	0.96
3_IND	Primary Copper Production	-											
3_IND	Primary Lead Production	-											
3_IND	Primary Nickel Production	-											
3_IND	Primary Zinc Production	-											
3_IND	*Other emission in Industry*												
4_SPU	*Emission from Solvent Use*												
5_ROT	Road Transport (Exhaust)	-											
5_ROT	*Other Road Transport emission*												
6_NRT	*Non-Road Transport*												
7_WAS	Clinical Waste Incineration	-											
7_WAS	*Other emission from Waste Generation and Disposal*												
8_AGR	*Emission from Agriculture*												
	Total sectors listed above			10633	16.74	8.55	46.34	12.17	51.35	380.21	16.66	8.65	4.83

Table 17 *Emission in 2020 after full implementation of the HM Protocol and emission reduction after a possible revision of the HM Protocol, associated emission reduction and costs for the non-EU(25)+ for Package 1 and Package 2, re-spectively.*

Sector	Detailed Sub-Sector	Detailed Fuel	Emission 2020 FI existing HM Protocol (tonnes) As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	4.11	9.61	1.24	16.52	24.30	2.83	19.17		100.89
1_PHP	Heat / Power Plants	Hard Coal	18.73	6.07	2.52	50.09	53.97	9.88	302.97	13.69	612.13
1_PHP	Heat / Power Plants	Heavy Fuel Oil	18.21	17.13	43.50	16.78	5.45	890.84	30.07	16.48	3.48
1_PHP	Heat / Power Plants	Peat	0.02	0.05	0.01	0.08	0.12	0.01	0.10		0.02
1_PHP	*Other emission from Heat/Power Plants*		*0.26*	*0.22*	*0.36*	*0.75*	*0.07*	*1.95*	*1.21*	*0.06*	*54.43*
2_RCO	*Residential, commercial and other combustion*		*16.61*	*16.17*	*59.88*	*130.39*	*19.64*	*161.19*	*143.47*	*7.59*	*609.84*
3_IND	Cement Production	-	0.39	0.42	1.15		33.93	3.27	4.31	0.10	7.46
3_IND	Chlorine Production	-					2.62				
3_IND	Coke Ovens	-	4.15	10.81	35.26	18.67	6.25	13.48	46.62		45.63
3_IND	Glass Production	-	0.53	1.32	11.01	2.85	0.22	8.72	82.23	81.87	53.60
3_IND	Industrial Combustion	Brown Coal	0.00	0.01	0.00	0.01	0.06	0.00	0.01		0.06
3_IND	Industrial Combustion	Hard Coal	0.11	0.05	0.18	0.29	1.02	0.42	1.93	0.14	3.35
3_IND	Industrial Combustion	Heavy Fuel Oil	3.93	4.23	8.58	3.77	1.09	163.10	7.66	3.08	0.76
3_IND	Industrial Combustion	Peat	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
3_IND	Iron & Steel, Blast furnaces	-	12.43	1.72	7.78	68.84	1.97	18.23	421.93	3.38	1237.62
3_IND	Iron & Steel, Electric Arc Furnace	-	0.61	2.63	6.61	5.90	0.13	0.75	14.96	0.65	141.94
3_IND	Iron & Steel, Oxygen Furnace	-	1.15	2.02	7.64	7.64	0.23	3.82	117.87	0.23	305.47
3_IND	Iron & Steel, Sinter Production	-	1.22	3.12	5.87	15.02	1.92	18.52	184.05	0.80	29.36
3_IND	Oil Refineries	Hard Coal	0.00	0.00	0.01	0.01	0.06	0.02	0.03	0.00	0.17
3_IND	Oil Refineries	Heavy Fuel Oil	0.78	0.97	1.85	0.73	0.23	35.25	1.47	0.64	0.15
3_IND	Primary Copper Production	-	49.39	19.69		240.40	0.16		98.47		490.89
3_IND	Primary Lead Production	-	1.08	2.16		2.89	1.27		179.92		28.40
3_IND	Primary Nickel Production	-			236.74			92.33			
3_IND	Primary Zinc Production	-		8.57			4.37		21.28		426.42
3_IND	*Other emission in Industry*		*18.51*	*12.30*	*46.64*	*64.79*	*14.27*	*253.18*	*250.34*	*9.19*	*592.93*
4_SPU	*Emission from Solvent Use*										
5_ROT	Road Transport (Exhaust)	-							1102.00		
5_ROT	*Other Road Transport emission*			*1.63*	*7.40*	*188.13*		*11.12*		*1.01*	*390.17*
6_NRT	*Non-Road Transport*		*0.82*	*0.41*	*0.60*	*184.05*	*0.08*	*28.14*	*105.23*	*0.65*	*8.19*
7_WAS	Clinical Waste Incineration	-	0.00	0.03	0.00	0.01	0.26	0.00	0.96	0.00	0.16
7_WAS	*Other emission from Waste Generation and Disposal*		*0.02*	*0.09*	*0.14*	*0.32*	*0.98*	*0.06*	*0.67*	*0.01*	*6.44*
8_AGR	*Emission from Agriculture*		*0.00*	*0.01*	*0.01*	*0.01*	*0.01*	*0.18*	*0.01*		
	Total sectors listed above		153	121	485	1019	175	1717	3139	140	5150

Sector	Detailed Sub-Sector	Detailed Fuel	Package 1 measure	Package 1 costs (M€)	Emission reduction Package 1 measures (tonnes) As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	S1-2	2264	2.36	5.55	0.89	10.57	1.40	1.78	11.07		59.07
1_PHP	Heat / Power Plants	Hard Coal	S1-2	2468	10.76	3.51	1.80	32.06	3.12	6.20	174.95	6.82	358.37
1_PHP	Heat / Power Plants	Heavy Fuel Oil	S1-1	68	11.49	10.87	35.60	11.94	0.35	632.11	19.08	9.02	2.23
1_PHP	Heat / Power Plants	Peat	S1-2	18	0.01	0.03	0.00	0.05	0.01	0.01	0.06		0.01
1_PHP	*Other emission from Heat/Power Plants*												
2_RCO	*Residential, commercial and other combustion*												
3_IND	Cement Production	-	S1-6	156	0.11	0.12	0.52		0.98	1.20	1.24	0.03	2.17
3_IND	Chlorine Production	-	S1-10	1					1.96				
3_IND	Coke Ovens	-	S1-11	1241	0.98	2.58	17.63	6.74	0.15	4.47	11.11		11.63
3_IND	Glass Production	-	S1-9	9	0.37	0.92	8.74	2.07	0.02	6.53	57.56	49.41	37.52
3_IND	Industrial Combustion	Brown Coal	S1-2	5	0.00	0.00	0.00	0.01	0.00	0.00	0.01		0.03
3_IND	Industrial Combustion	Hard Coal	S1-2	50	0.06	0.03	0.13	0.19	0.06	0.26	1.12	0.07	1.96
3_IND	Industrial Combustion	Heavy Fuel Oil	S1-1	13	2.47	2.68	7.02	2.67	0.07	115.59	4.85	1.69	0.49
3_IND	Industrial Combustion	Peat	S1-2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
3_IND	Iron & Steel, Blast furnaces	-	S1-12	84	6.25	0.87	5.28	38.73	0.10	10.76	213.22	1.48	627.89
3_IND	Iron & Steel, Electric Arc Furnace	-	S1-3	242	0.09	0.38	2.77	1.42	0.00	0.21	2.17	0.08	21.31
3_IND	Iron & Steel, Oxygen Furnace	-	S1-14	527	0.91	1.62	6.82	6.45	0.02	3.18	94.43	0.16	246.56
3_IND	Iron & Steel, Sinter Production	-	S1-13	321	0.59	1.51	4.03	8.45	0.09	10.57	89.01	0.34	14.40
3_IND	Oil Refineries	Hard Coal	S1-2	6	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.10
3_IND	Oil Refineries	Heavy Fuel Oil	S1-1	3	0.49	0.61	1.51	0.52	0.01	24.84	0.93	0.35	0.10
3_IND	Primary Copper Production	-	S1-4	101	36.53	14.64		191.52	0.01		73.20		367.35
3_IND	Primary Lead Production	-	S1-16	17	0.54	1.08		1.76	0.06		89.96		14.62
3_IND	Primary Nickel Production	-	S1-5	22			226.67			85.50			
3_IND	Primary Zinc Production	-	S1-15	22		6.43			0.33		15.96		323.02
3_IND	*Other emission in Industry*												
4_SPU	*Emission from Solvent Use*												
5_ROT	Road Transport (Exhaust)	-	S1-7								1014.36		
5_ROT	*Other Road Transport emission*												
6_NRT	*Non-Road Transport*												
7_WAS	Clinical Waste Incineration	-	S1-8	0					0.10				
7_WAS	*Other emission from Waste Generation and Disposal*												
8_AGR	*Emission from Agriculture*												
	Total sectors listed above			7637	74	53	319	315	9	903	1874	69	2089

Sector	Detailed Sub-Sector	Detailed Fuel	Package 2 measure	Package 2 costs (M€)	Emission reduction Package 2 measures (tonnes) As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	S2-2	3053	4.11				19.44				
1_PHP	Heat / Power Plants	Hard Coal	S2-2	3328					43.18				
1_PHP	Heat / Power Plants	Heavy Fuel Oil	S2-1	342	18.21	17.13	43.50	16.78	5.45	890.84	30.07	16.48	3.48
1_PHP	Heat / Power Plants	Peat	S2-2	24					0.10				
1_PHP	*Other emission from Heat/Power Plants*												
2_RCO	*Residential, commercial and other combustion*												
3_IND	Cement Production	-	S2-3	964					6.79				
3_IND	Chlorine Production	-	S2-4	29					2.62				
3_IND	Coke Ovens	-											
3_IND	Glass Production	-											
3_IND	Industrial Combustion	Brown Coal	S2-2	7					0.05				
3_IND	Industrial Combustion	Hard Coal	S2-2	67					0.82				
3_IND	Industrial Combustion	Heavy Fuel Oil	S2-1	65	3.93	4.23	8.58	3.77	1.09	163.10	7.66	3.08	0.76
3_IND	Industrial Combustion	Peat	S2-2	0					0.00				
3_IND	Iron & Steel, Blast furnaces	-											
3_IND	Iron & Steel, Electric Arc Furnace	-											
3_IND	Iron & Steel, Oxygen Furnace	-											
3_IND	Iron & Steel, Sinter Production	-											
3_IND	Oil Refineries	Hard Coal	S2-2	9					0.05				
3_IND	Oil Refineries	Heavy Fuel Oil	S2-1	14	0.78	0.97	1.85	0.73	0.23	35.25	1.47	0.64	0.15
3_IND	Primary Copper Production	-											
3_IND	Primary Lead Production	-											
3_IND	Primary Nickel Production	-											
3_IND	Primary Zinc Production	-											
3_IND	*Other emission in Industry*												
4_SPU	*Emission from Solvent Use*												
5_ROT	Road Transport (Exhaust)	-											
5_ROT	*Other Road Transport emission*												
6_NRT	*Non-Road Transport*												
7_WAS	Clinical Waste Incineration	-											
7_WAS	*Other emission from Waste Generation and Disposal*												
8_AGR	*Emission from Agriculture*												
	Total sectors listed above			7928	27	22	54	21	80	1089	39	20	4

4.1.1 Large Combustion Plants (Heat/Power Plants, Petroleum Refineries and other Industrial Combustion)

The ELVs of combustion of coal and heavy fuel oil by Heat/ Power plants > 50 MWth are selected for possible revision because of their high relevance for almost all heavy metals (Table 9 and Table 10). The majority of countries in country group 1 (EU(25)+) is expected to implement both the EU IPPC Directive as well as the UNECE 2nd Sulphur Protocol. Larger coal-fired installations will therefore be equipped with flue gas desulphurization (FGD) and BAT to control the emission of other pollutants. This is regarded as autonomous development in this country group. Most likely this implies that no additional effort will be needed to achieve the ELVs of a revised HM Protocol and no real remaining potential to further reduce emissions for coal-fired plants.
The non-EU(25)+ countries have no obligation to implement the IPPC Directive and only a part of this country group has ratified the 2nd Sulphur Protocol. To achieve a revised ELV of 20 mg/Nm^3 a significant effort needs to be made in order for all coal-fired capacity in this country group to meet this standard, even when selecting the most cost efficient way of retrofitting with fabric filters instead of opting for an integrated multi-pollutant strategy. This is further amplified by Central and Eastern Europe's heavy usage of coal. As a result the costs are estimated at almost € 5 billion annually for this country group. This is by far the most expensive measure to take in the Package 1 revision of the HM Protocol. It should be noted that a similar effort will be needed in large parts of EU(25)+ but these costs are regarded as being the result of (autonomous) implementation of (EC) policy and not attributed to a revised HM Protocol.

The situation for heavy oil-fired plants is somewhat different since at this moment particulate matter removal is not common practice for heavy oil-fired plants, nor is it regarded as BAT by IPPC. However, meeting an ELV of 20 mg/Nm^3 is not possible without end-of-pipe flue gas cleaning. Therefore, in both country groups all oil-fired heat/power generating capacity that use residual oil as main fuel will have to be equipped with ESP to comply with the proposed revised standard. This applies to the generation of electricity where heavy fuel oil is mostly used a secondary fuel, oil refineries and large combustion plants in industry. For both country groups, but notably for non-EU(25)+, this leads to costs of several tenths of million of Euros annually (Table 16 and Table 17). Implementation of PM emission abatement from residual oil-fired plants especially reduces the Ni emission in UNECE-Europe.

Package 2 Hg emission control is not foreseen to be implemented as autonomous policy in UNECE Europe. For large coal-fired combustion plants the option of activated carbon injection has been evaluated (last columns, Table 16 and Table 17), which would result in extremely high costs in both country groups, amounting to a total in excess of € 14 billion annually. For residual oil-fired large combustion plants a fuel-switch to natural gas has been considered. The costs of this option are considered as being fairly high (> € 600 million) given the relatively small share of residual oil in total use of energy in Europe. In addition, a massive fuel-switch to natural gas might influence market prices of gas, making costs even higher. Moreover – but outside the scope of the present study – an alternative use would have to be found for the heavy residue from oil refining (e.g. processing into petro coke) that should at least result in no increased HM. Emissions from other sources. Nevertheless, for certain uses like petroleum refineries, a fuel switch to natural gas could be a viable option to reduce emission, as sulphur emission would be eliminated too.

4.1.2 Iron and steel industry

For the EU(25)+ it is estimated that autonomous policy will fall short in meeting the revised ELVs for two processes; 1) iron ore sinter plants in the primary and, 2) electric arc furnaces in the secondary iron and steel industry (see section 3.3 and 3.6). Further measures to achieve the revised ELVs would result in total costs of about € 1 billion annually (Table 16). Other processes in the iron and steel sector are expected to meet the revised ELVs as a result of the IPPC Directive. However, if a proposal to revise the HM Protocol reaches a more definitive stage it is recommended that additional research is carried out to exactly determine the current day emissions from the above named processes.

For the non-EU(25)+ countries autonomous policy is expected to be less stringent compared to currently foreseen policy in the EU(25). This results in a greater number of processes that have to be equipped with additional particulate matter control to meet the revised emission standards. The costs in the iron and steel sector of the measures needed are estimated to be around 2.4 billion € per year (Table 17). Although the costs are considerable for the non-EU(25)+ countries, the potential for emission reduction is also substantial.

4.1.3 Non-ferrous metals production (primary production of Cu, Zn, Pb and Ni)

The proposed revised ELVs for the non-ferrous metal production industry are expected not to be met as a result of any autonomous policy in UNECE-Europe. This implies that for both country groups additional measures, such as retrofitting fabric filters to existing non-ferrous metal smelters, will be necessary. The estimated cost of such measures are ~ M€ 250 for EU(25)+ (Table 16) and ~ M€ 160 for non-EU(25)+ (Table 17). Copper smelters rank highest in terms of investments needed. There is again the issue of whether or not the implementation of the IPPC Directive will be sufficient to meet the revised ELVs in the EU(25)+ group. Currently our expert judgement is that this will not be the case (see also sections 3.7 -3.10). However, provided that the IPCC Directive will be sufficient to meet the revised

ELVs, the costs as well as reduction potentials will be attributed to autonomous measures in the non-ferrous metal works in Table 16 (and hence would be reported as zero here).

4.1.4 Cement production

For the EU(25)+ it is expected that the implementation of the IPPC Directive will result in achieving the revised ELV of 15 mg PM/Nm^3. This does not apply to the non-EU(25)+ countries and annual cost of measures to meet this standard are estimated at ~ M€ 160 (Table 17).
The key source analysis of sector contributions (section 2.4, Table 9 and Table 10) indicates that cement production is an important contributor to Hg emissions in UNECE Europe. Therefore, Package 2 measures focussing on Hg emission reduction specifically address cement production. Rentz et al. (2004a) suggests an ELV of 0.05 mg Hg/Nm^3 for cement plants. If this ELV is to be achieved by end-of-pipe control techniques all European UNECE countries need to do considerable investments. Injection of activated carbon would bring about costs ranging from over € 1.5 billion per year for the EU(25)+ and close to € 1 billion per year for non-EU(25)+ (Table 16 and Table 17, respectively). It is possible that after this measure is taken, Hg emission will be far below the ELV of 0.05 mg Hg/Nm^3 (not taken into account in our calculations). Other substances such as dioxines might be reduced as well. The need for these expensive end-of-pipe measures may be reduced by a careful selection of fuels (favouring those with a low Hg content) since current Hg emission from cement production is relatively close to the revised ELV.

4.1.5 Chlorine production

According EuroChlor (2004) a revised ELV of 0.5g Hg/tonne Cl_2 will be achieved by all of its members by the year 2020. In fact, Eurochlor indicates that by the year 2020 the Hg-based chlorine production process will have been abandoned completely by its Members. The chlorine production industry in the EU(25)+ has almost entirely joined Eurochlor. Introducing a revised ELV in the EU(25)+ will therefore be basically cost-neutral. Eurochlor has also members within the non-EU(25)+ country group and meeting the revised ELV is possible at modest costs (about € 1 million annually).
Package 2 strategy comprises the complete conversion of remaining Hg-based production capacity to Hg-free process types. Although this is basically a very expensive measure, remaining Hg-based capacity is estimated to be low in Europe to such an extent that required investments appear relatively low as well (about M€ 30 annually for the non-EU(25)+, Table 17).

4.1.6 Road transport

In Section 3.16 a rather extensive discussion addresses the reason why gasoline-powered vehicles seem to remain an important source of Pb emission in 2020, in spite of the widespread use of unleaded gasoline. As a worst case scenario (and lacking accurate data) the UNECE limit value (0.013 g/l) has been used as default emission factor for non-EU countries if no official data were available. The UNECE HM Protocol standard for Pb content of unleaded fuel (0.013 g/l) is rather high to limit problems due to occasional contamination of unleaded fuel by residues of leaded gasoline present in e.g. storage tanks. However, as leaded gasoline will be phased out completely in Europe, a tighter standard of 0.005g Pb/l will probably be met without any additional costs. Moreover, there seems to be a positive discrepancy between the limit value of 0.005 g/l and the actual Pb content of unleaded gasoline (Table 12) and default emissions are calculated using 0.001 g/l. The resulting Pb emission reduction is according to our calculations highly relevant. However, it should be noted that this is due to adjusting of default values – it may have limited impact on real-world emissions as was also discussed in section 3.16. Clearly, as is also pointed out in chapter 3, additional research is needed to accurately define present-day residual Pb content in unleaded fuel for each country.

4.1.7 Medical waste incineration

The revised ELVs for medical waste incineration comprise a limit value for dust as well as for Hg. Similar ELVs would apply as for municipal and hazardous waste. Although the required measures are sophisticated, the estimated costs are relatively low. This is because the total amount of hospital waste is small compared to other waste streams.

4.1.8 Glass production

For the EU(25)+ countries it is expected that by 2020 the revised ELV of 30 mg PM/Nm^3 will be met as a result of the implementation of the IPPC Directive. For the non-EU(25)+ countries costs of ~ M€ 10 are foreseen to meet the new ELV. Especially Se emissions and to a lesser extend Pb emissions will be reduced as a result (Table 17).

4.2 The relative HM emission reduction due to a revised HM Protocol

The relative emission reduction achieved by a revision of the HM Protocol can be expressed as fraction of the total UNECE-Europe emissions. The relative decrease of emissions by metal as a result of tightening the Protocol ELVs following

Package 1 is presented in Figure 1. Revision of the HM Protocol following the Package 1 measures is effective to the Cd and Pb emission in UNECE-Europe as well as Cr and Ni emissions (Figure 1). The reduction achieved in the EU(25)+ is (for every individual HM) lower than the emission reduction achieved in the non-EU(25)+ countries. This is because it is assumed that the implementation of the IPPC Protocol (and other EC Directives) is autonomous policy for the EU(25)+ countries. It can be seen that the effectiveness of emission reduction for Cu, As, Se and Zn lags behind a bit. Road transport is an important source of Cu and Zn emissions and not specifically addressed in the revised Protocol, hence the limited impact.

Mercury emissions are only marginally abated by Package 1 measures (see also Table 16 and Table 17) for both country groups (Figure 1.). The relative decrease of Hg emissions as a result of tightening the Protocol ELVs following Package 1 or Package 2 is presented in Figure 2. The increase in Hg emission reduction efficiency for both country groups is high and not surprising as Package 2 is especially designed to address the Hg emissions. The Package 2 - Hg removal techniques would boost the reduction potential to ~50% of the original 2020 emission (Figure 2). As a co-benefit the Package 2 measure “fuel switch from heavy fuel oil to gas”, will reduce other HM, especially Ni, as well.

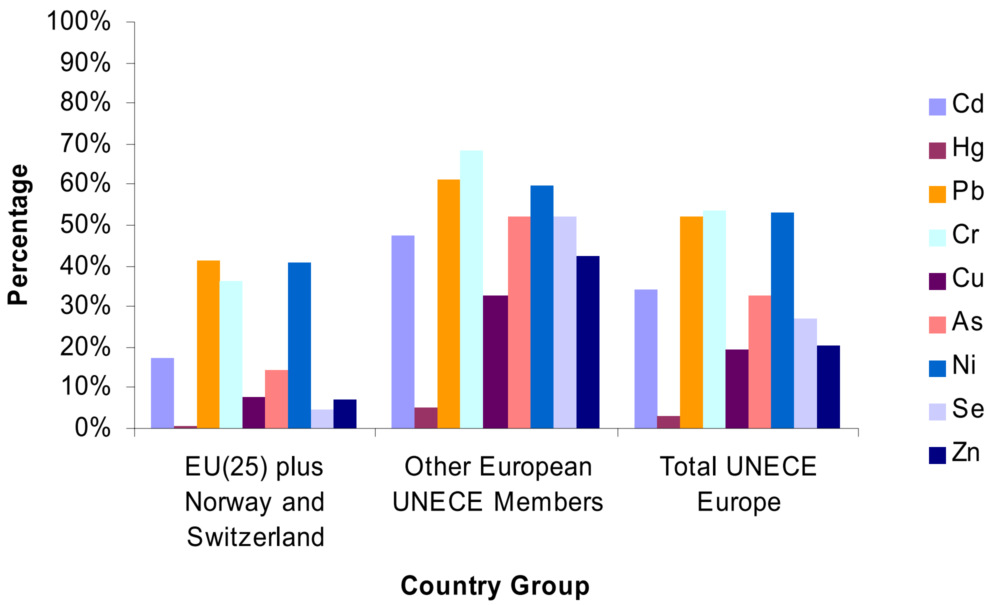

Figure 1 Emission reduction potential of a possible revision of the HM Protocol following Package 1.

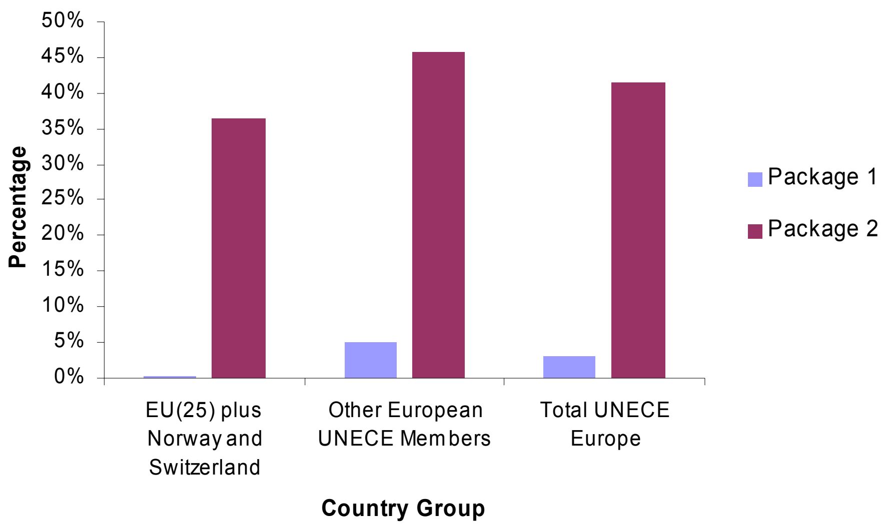

Figure 2 *Emission reduction potential of possible revision of the HM Protocol for mercury following Package 1 and Package 2.*

4.3 Emission reduction and associated costs upon revision of the HM Protocol by country group

The result of a revised HM Protocol and its costs are aggregated and presented in Table 18. The relevance of this exercise (and Table 18) is not to discuss the absolute emission level of a country group because the number of citizens covered, climatic conditions, prime economic activities etc. are fundamentally different between the two groups. The importance lies in the difference in associated costs and additional emission reduction achieved due to differences in autonomous policies implemented in both country groups. As a result the costs for the two Packages of revision defined in the present study are quite different. The total costs in UNECE-Europe for Package 1 measures is ~€ 9 billion but 85% of these costs will have to be made in the non-EU(25)+ countries. The primary reason for this is the fact that all costs related to the implementation of the IPPC Directive are excluded. By contrast the total costs in UNECE-Europe for Package 2 measures is ~€ 18.5 billion and ~60% of these costs will have to be made in the EU(25)+ countries. It can be (again) concluded that the additional Hg emission reduction achieved by Package 2 is not covered by autonomous policies in UNECE-Europe and a revised HM Protocol could be the major motivation and incentive to actively reduce Hg emissions. Please note that the emission reduction due to implementation of Package 1 and Package 2 is not the sum of the individual Package 1 and 2 emission reductions as listed in Table 18. So, for example implementation of Package 1 and 2 will not result in a Cd emission reduction of 68 + 31 = 99 tonnes/year for total UNECE. The total emission reduction will be less than 99 tonnes/year (but more than 68) because some double counting occurs – if a fuel switch is proposed for a certain sector in Package 2 than the reduction technique proposed in Package 1 for this sector will not be implemented. It is important to realize that if Package 2 is implemented only a few measures of Package 1 become redundant. For example, a fuel switch in refineries from heavy fuel oil to gas makes additional dust removal no longer necessary. However, to realize the full reduction potential of Package 1 and 2 almost all costs listed in the individual Package 1 and 2 Tables need to be made. The emission reduction due to a possible revision of the HM Protocol involving both Package 1 and 2 is presented in Table 18 as well as the costs involved implementing both Packages.

Table 18 Emission of heavy metals in UNECE Europe in 2020 before and after revision of the HM Protocol following two separate revision Packages and achieved emission reductions and costs for Package 1 and 2.

Country group	Emission in 2020 after full implementation of 1998 HM Protocol[a)] (tonnes)									Costs (M€)
	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	
EU(25)+	95	141	2622	165	415	1107	904	155	8615	
non-EU(25)+	121	175	3139	153	485	1019	1717	140	5150	
UNECE Europe	217	316	5761	318	900	2126	2622	294	13766	
	Emission after Protocol Revision (tonnes) - Package 1									
EU(25)+	81	141	1548	148	276	1026	613	149	8000	
non-EU(25)+	68	166	1265	79	166	704	814	70	3061	
UNECE Europe	149	307	2812	227	442	1729	1427	220	11061	
	Emission Reduction due to Revision (tonnes) - Package 1									*Package 1*
EU(25)+	14	0.4	1074	17	139	81	291	5	615	1344
non-EU(25)+	53	9	1874	74	319	315	903	69	2089	7637
UNECE Europe	68	9	2949	91	458	396	1194	75	2704	8981
	Emission after Protocol Revision (tonnes) - Package 2									
EU(25)+	87	90	2605	148	369	1095	524	146	8610	
non-EU(25)+	99	95	3100	130	431	998	628	119	5146	
UNECE Europe	186	185	5705	278	800	2093	1152	266	13756	
	Emission Reduction due to Revision (tonnes) - Package 2									*Package 2*
EU(25)+	9	51	17	17	46	12	380	9	5	10633
non-EU(25)+	22	80	39	23	54	21	1089	20	4	7928
UNECE Europe	31	131	56	40	100	33	1469	29	9	18560
	Emission after Protocol Revision (tonnes) - Package 1+2									
EU(25)+	77	90	1540	141	265	1021	467	145	7998	
non-EU(25)+	60	95	1250	71	156	698	497	61	3060	
UNECE Europe	137	185	2790	211	421	1719	964	206	11057	
	Emission Reduction due to Revision (tonnes) - Package 1+2									*Package 1+2*
EU(25)+	18	52	1082	24	151	86	438	10	617	11936
non-EU(25)+	62	81	1889	82	329	321	1220	79	2090	15454
UNECE Europe	80	132	2971	107	480	407	1657	89	2708	27391

Projected annual emissions of heavy metals in 2020 following IIASA CLE-BL scenario and assuming all UNECE countries ratify the HM Protocol before 2010 (Denier van der Gon et al, 2005).

4.3.1 Costs and impact of specific Hg reduction measures

The measures defined as Package 2 specifically aim at reducing the emission of Hg because the emission is poorly mitigated by generic dust emission reduction measures. The results of implementation of Package 2 have been listed in Table 16 and Table 17, and summarized in Table 18. The results show that emission reduction achieved by implementation of Package 2 measures is little influenced by autonomous measures. The specific removal of Hg is currently not a part of any autonomous measures. To facilitate discussion on the impact of Package 2 measures for Hg reduction, the impact and costs by source sector for UNECE-Europe have been aggregated in Table 19. This duplicates to some extend the information provided in Table 16, Table 17 and Table 18 but is thought to be a useful addition for insight of the possibilities to address Hg emissions in UNECE-Europe. Table 19 indicates that after full implementation of the 1998 HM Protocol, ~ 60% of the remaining Hg emissions in 2020 from UNECE-Europe can be reduced by Package 2 measures at a cost of € ~ 18.5 billion. The sectoral data shown in Table 19 demonstrate that unfortunately there are no cheap measures that reduce a large portion of the Hg emission. Please note that the sum of Hg emission reduction due to a possible Package 2 revision in Table 19 equals the emission reduction listed in Table 18 (131 tonnes) but the remaining emission listed in the two Tables is different because not all sources are listed in Table 19.

Table 19 Selected source categories, fuel type, proposed measures, costs and emission reduction of implementing a possible revised HM Protocol aiming at specific Hg reduction (Package 2) on 2020 Hg emissions in UNECE-Europe.

Source Category	Fuel	Applied measure Package 2	Cost (M€/yr)	Hg Emission Reduction (tonnes/yr)	Cost effec-tiveness Hg (€/g)
Heat / Power Plants	Solid fuels	Specific removal of Hg from coal-fired large combustion plants by in-jection of activated carbon, 80% removal efficiency	14496	96.5	150
	Liquid fuels	Fuel switch from heavy fuel oil to natural gas	421	6.3	67
Industrial Combustion (incl. Oil Refineries)	Solid fuels	Specific removal of Hg from coal-fired large combustion plants by njection of activated carbon, 80% removal efficiency.	796	4.7	168
	Liquid fuels	Fuel switch from heavy fuel oil to natural gas	201	2.8	4
Cement Production		Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05 mgHg/Nm^3	2617	18.2	144
Chlorine Production		Complete conversion from Hg-based to Hg-free process	29	2.6	11

4.4 The contribution of residential sources

The key source analysis described in chapter 2 indicated that ~10% of all emissions for each HM is caused by residential sources such as combustion of wood (Table 5). In consultation with the commissioner of the project it has been decided not to evaluate the potential of emission reduction by addressing residential /domestic combustion sources. The main motivation for this choice is the foreseen difficulties in legislation, implementation and enforcement of relevant emission control measures. Measures for this source category quickly come down to e.g. a ban on using wood for residential heating or a forced abandoning of coal stoves. The residential combustion sector meets the criteria of more than 5% of the total emission of a specific HM and is an important source of HM. 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 as suggested by Denier van der Gon et al. (2005). 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. It should be clearly noted that excluding this sector in the revision of the HM Protocol does not imply that it is not an important source.

4.5 Spatial distribution of emission data

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. 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 upon revision of the HM Protocol, the 2020 emission data assuming full implementation of the proposal for a revised HM Protocol 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. (1997), but the geographical proxy data have been updated to the year 2000. An example of the gridded emissions for cadmium upon revision of the HM Protocol is presented in Figure 3. In Figure 4 the spatial distribution of the Hg emission reduction due to a possible revision of the Protocol is depicted. It can be seen that the emission reduction is mainly localized at specific points or areas. This is because domestic/residential sources and transport related sources, which have a more gradual diffuse distribution, are not explicitly addressed in this study. In countries where our knowledge of the spatial distribution of activities is poor (e.g. Turkey, Figure 4) the emission is distributed by population density as the emissions are all anthropogenic. However, this is a poor representation of the actual location of the emission reduction.

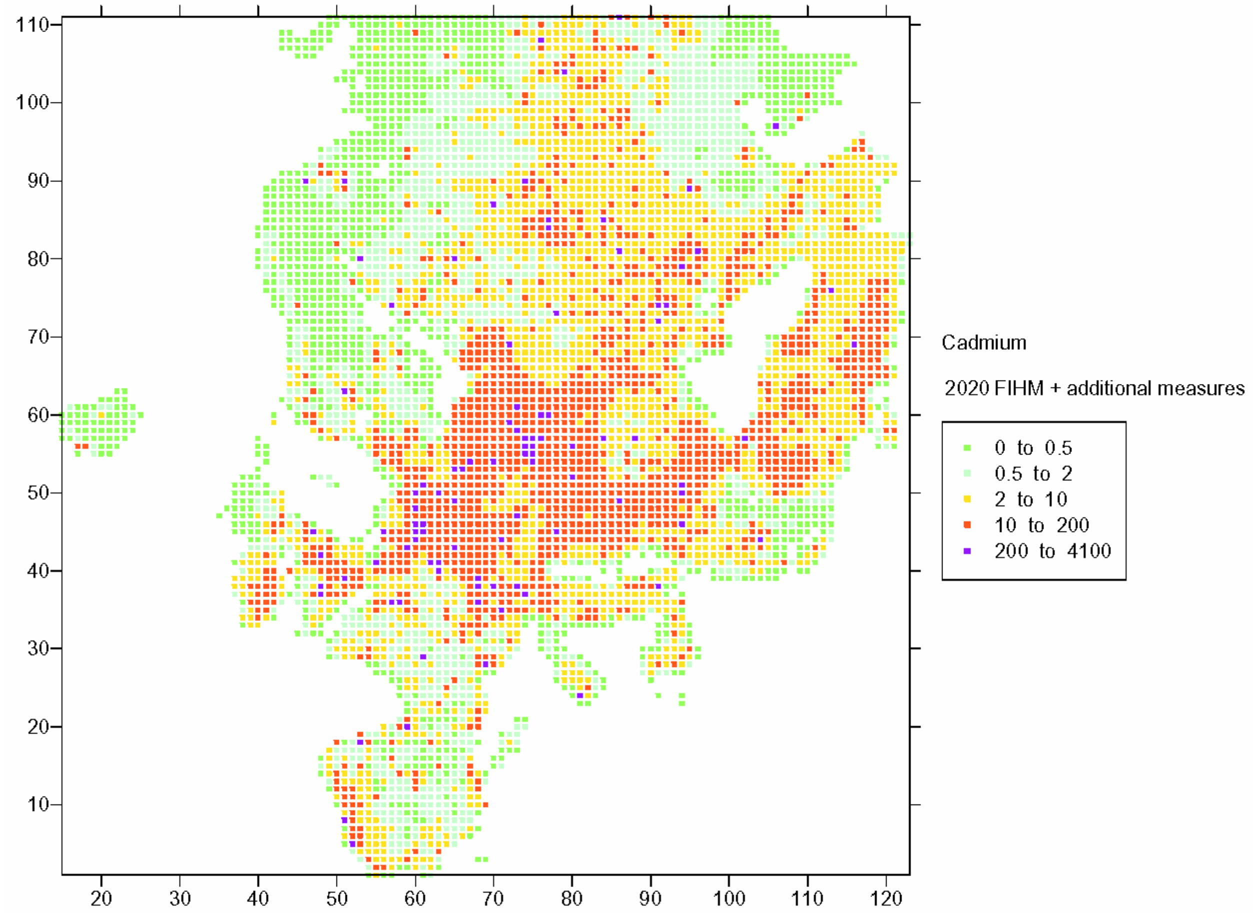

Figure 3 *Distribution of the emissions of cadmium over the 50 x 50 km² EMEP grid for UNECE-Europe in 2020 assuming full implementation of a possible revised HM Protocol.*

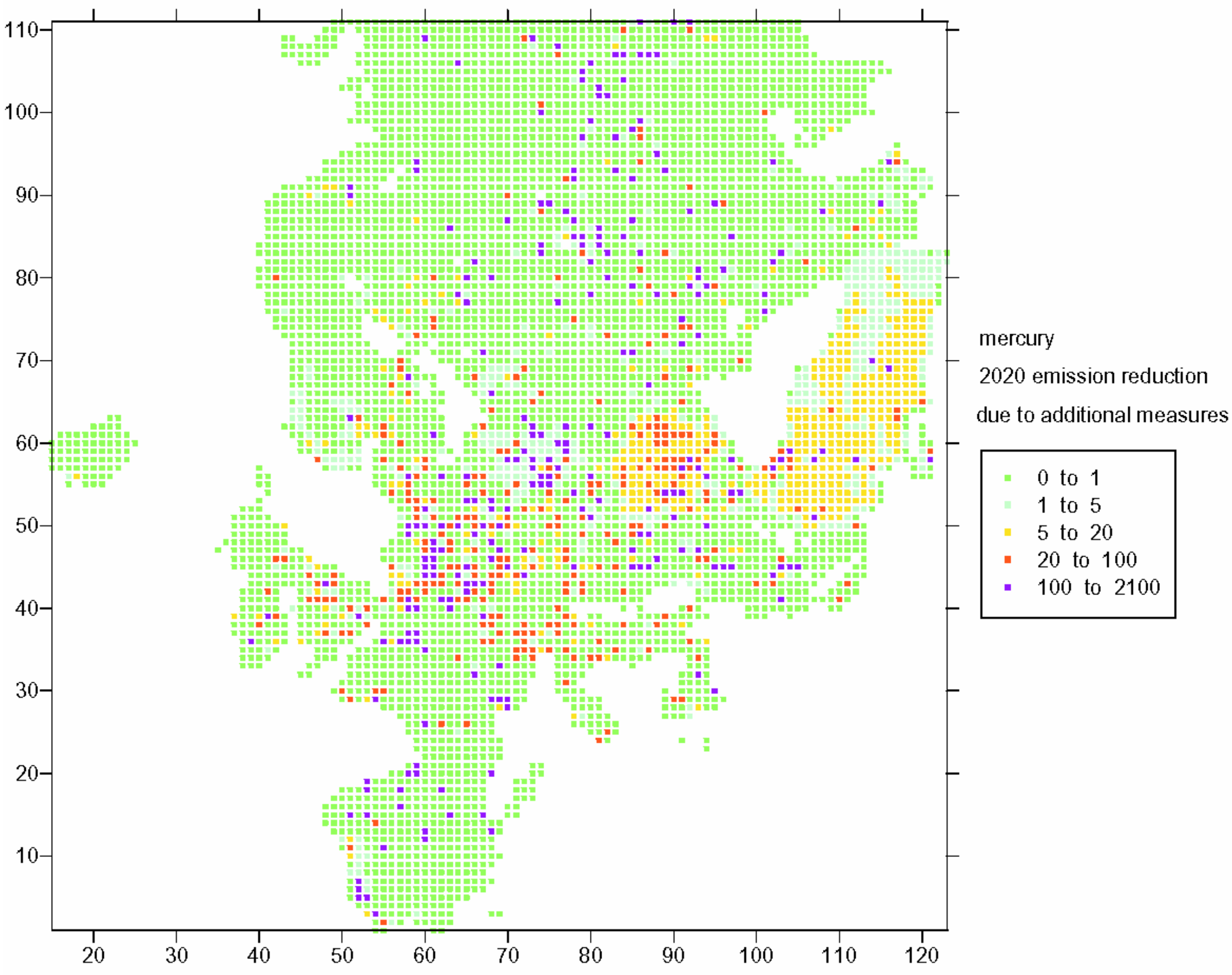

Figure 4 *Distribution of the emission reduction of mercury over the 50 x 50 km² EMEP grid for UNECE-Europe in 2020 assuming full implementation of a possible revised HM Protocol.*

4.6 Quantification of side effects for particulate matter

The revision of the HM Protocol following the set of measures as proposed in this study will have a side-effect on particulate matter (PM) emissions because the measures often result in further dust emission control. A first order estimate of the PM emission reduction following the implementation of the Package 1 and Package 2 measures is presented in Table 20. To put these emission reductions into perspective we can compare them to the PM emissions in 2020 as calculated by IIASA (2006) for the CAFE programme following the CP_CLE_Aug04 (Nov04) scenario (Table 21). The fraction of the respective sector emissions that would be reduced upon implementation of the measures of a revised HM Protocol are shown in the last 3 columns of Table 20. The results indicate that a substantial part of the remaining PM emissions from Heat and power production will be reduced. For the industrial combustion and production processes as well as for the total (all sectors) PM emissions the impact of implementation of a revised HM Protocol is positive but quite limited (1-2% reduction). It should be noted that these relative reduction fractions can only be seen as indicative of the order of magnitude. The most important limitation is that in our current study we assume full implementation of all autonomous measures (e.g. EU Directives) as well the 1998 UNECE HM Protocol. However, no PM emission data for this policy scenario are readily available and the best alternative is the data listed in Table 21. However, if the scenario used to generate the data in Table 21 would also include full implementation of the HM Protocol than PM emissions would most likely be somewhat lower and the relative reduction shown in Table 20 would increase. So, given the range of the data in Table 20 it can be concluded that possible revision of the HM Protocol will have a positive influence on PM emissions in UNECE-Europe but will not cause major PM emission reductions because some important PM emitting source categories (road transport, agriculture) are not addressed by a possibly revised HM Protocol. Moreover, full implementation of the 1998 HM Protocol in all UNECE-Europe countries, which is the starting point of the possible revision proposed in this study, already results in important reductions of PM emissions from HM emitting sources as a co-benefit (~ 3.7 Mtonnes TSP, 1.2 Mtonnes PM10 and 0.28 Mtonnes PM2.5 (Denier van der Gon et al., 2005))

Table 20 Estimated particulate matter emission reduction upon implementation of the possible revision of the HM Protocol as proposed in the present study.

Sector	TSP	PM10	PM2.5	TSP	PM10	PM2.5
	ktonnes			% reduction of sector emissions in Table		
Power	49.6	40.5	32.9	7%	10%	15%
Industry[a)]	46.5	24.1	16.9	2%	2%	2%
Total	96.1	64.6	49.8	1%	1%	2%

a) Includes sectors SNAP 3 Combustion in manufacturing industry and SNAP 4 Production processes of Table 21.

Table 21 Particulate matter emission for UNECE-Europe[a)] in 2020 following the CP_CLE_Aug04 (Nov04) scenario (IIASA, 2006).

Source sector	TSP	PM10	PM2.5
Corinair SNAP1 code	ktonnes		
1:Combustion_in_energy_industries	708.5	419.3	212.9
2:Non-industrial_combustion_plants	2291.4	1221.1	842.2
3:Combustion_in_manufacturing_industry	710.8	403.7	274.5
4:Production_processes	1458.9	894.6	575.6
5:Extraction_and_distribution	149.7	78.5	9.2
6:Solvent_use	0.0	0.0	0.0
7:Road_transport	1146.3	371.5	251.1
8:Other_mobile_sources_and_machinery	588.8	558.6	528.8
9:Waste_treatment_and_disposal	159.0	149.4	139.8
10:Agriculture	1322.0	480.8	205.5
Total	8535.4	4577.4	3039.6

a) The domain covered by the IIASA data does not include Armenia, Azerbaijan, Georgia, Kazakhstan and Kyrgyzstan.

4.7 Cost-effectiveness of measures in a revised HM Protocol

The cost effectiveness of a measure for a particular substance is calculated as the achieved emission reduction divided through its cost. The outcome is called the specific cost and denotes the amount of avoided emission for a substance per monetary unit. The specific costs for all emission control measures under Package 1 and Package 2 have been aggregated for UNECE Europe (Table 22). The cost effectiveness as presented in Table 22 is surrounded by large uncertainties as both the uncertainty of emission data and especially the estimated costs are significant. In general it can be said that specific costs of comparable order of magnitude (e.g. 97 and 166) are not significantly different as the uncertainty in the cost data from Table 22 easily amounts to a factor of 2-3. In addition it should be remarked that a particular measure can demonstrate a favourable cost effectiveness for one HM while for another only little reduction is achieved at relatively high cost by that same measure. Specific costs should therefore be interpreted for each HM individually. It is also a necessity because we have currently no (undisputed) method to compare or add up emission reduction of different HM. For example: How much Cd emission equals a ton of Zn emission? Only when an answer to this question of “weighing” the importance of HM is given, a balanced judgement of the co-benefits of each measure can be accounted for in monetary terms.

Assuming all autonomous measures such as the EU IPPC Directive and the UNECE 1998 HM Protocol have been implemented, the addition of electrostatic precipitators (ESP) to residual oil-fired large combustion plants appears to be the most cost-efficient way to further reduce Cd emissions. Only those combustion

plants that are primarily oil-fired have not been equipped with ESP yet and leave the possibility to implement this measure. Plants that use residual oil as secondary fuel are usually already equipped with ESP. Other relatively cost-effective measures to further reduce Cd emissions can be found in the non-ferrous metals sector and the glass industry (Table 22)
The possible measures for further Hg emission reduction show comparable cost-effectiveness for all sources (Table 22). Only the cost of Hg reduction in the chloro-alkali industry has a lower than average specific cost, but there the potential for further Hg reduction in this sector is small. A fuel switch from heavy fuel oil to natural gas seems to be a relatively cost efficient way to further reduce Hg emission. However, the difficulty with this measure is the uncertainty concerning the fate of the heavy fuel oil not fired in these combustion plants. If this is simply used elsewhere the corresponding Hg emissions could simply move to another source sector. A more expensive reduction measures is injection of activated carbon to large coal-fired combustion plants. The Hg emission reduction potential of this source is considerable. The injection of activated carbon will also have co-benefits such as the removal of specific other gaseous compounds, such as dioxins, provided that the abated Hg source is also a source of other gaseous pollutants.

Some measures may have very high specific costs for a particular metal (Table 22). This is caused by the fact that the source in question will have a very low and effectively negligible contribution to emission of that HM. Specific costs are nevertheless calculated and the total cost of the measure is in that case divided by a very small amount of avoided emission. The high specific costs that are thus calculated should be considered artefacts, as the measures where this occurs are targeted at other metals where more realistic specific costs are found.

The most cost-effective way to further reduce Pb emissions is lowering the Pb content of unleaded gasoline for countries where this is not yet mandatory (non-EU(25)+). This measure is regarded as cost-neutral and has a very large reduction potential. However, the real-world effectiveness is difficult to estimate as country specific Pb contents of unleaded gasoline are presently not available. Other cost effective measures for Pb could be taken in the primary Pb production sector, glass production industry and in blast furnaces in the iron and steel industry. All these sources appear to have significant Pb reduction potential. Measures in the primary Cu and Zn industry, for sinter plants and basic oxygen furnaces and for heavy oil/hard coal-fired power plants are found to have equally high reduction potentials, but the specific costs are higher (Table 22).

Table 22 *Source-sector specific costs, emission reduction and specific cost of emission reduction Cd, Pb, Hg and six other HM in 2020, for a possibly revised HM Protocol for UNECE-Europe, after full implementation of the 1998 HM Protocol.*

					Avoided emission (tonnes)									Cost effectiveness (€ / g avoided emission)								
Sector	Sub-sector	Fuel type	Measure	Annual costs (M€)	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	2264	5,55	1,403	11,1	2,36	0,9	10,6	1,8		59,1	408	1614	204	958	2546	214	1274		38
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	5801		29,697									195							
		Hard Coal	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	2468	3,51	3,116	174,9	10,76	1,8	32,1	6,2	6,82	358,4	704	792	14	229	1372	77	398	362	7
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	8486		66,198									128							
		Peat	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	18	0,03	0,007	0,1	0,01	0,0	0,1	0,0		0,0	633	2517	316	1562	4161	349	2076		1251
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	209		0,647									324							
		Heavy Fuel Oil	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20mgPM/Nm3	83	12,36	0,393	22,5	13,15	44,3	15,3	704,9	10,37	3,0	7	212	4	6	2	5	0	8	28
			Fuel switch from heavy fuel oil to natural gas	421	19,85	6,308	36,3	21,24	55,1	22,0	1009,2	19,32	4,9	21	67	12	20	8	19	0	22	86
3_IND	Industrial Combustion	Brown Coal	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	5	0,00	0,003	0,0	0,00	0,0	0,0	0,0		0,0	1391	1457	696	3353	7355	775	5775		144
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	52		0,205									254							
		Hard Coal	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	50	0,03	0,059	1,1	0,06	0,1	0,2	0,3	0,07	2,0	1848	843	44	790	385	267	187	698	25
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	623		4,099									152							
		Peat	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	0	0,00	0,000	0,0	0,00	0,0	0,0	0,0		0,0	1381	4322	142	1108	7492	193	7744		892
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	10		0,014									689							
		Heavy Fuel Oil	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20mgPM/Nm3	27	4,53	0,120	8,3	6,40	21,1	5,3	208,9	3,31	1,9	6	224	3	4	1	5	0	8	14
			Fuel switch from heavy fuel oil to natural gas	136	7,60	2,018	13,9	11,11	27,4	7,8	314,8	6,50	3,2	18	67	10	12	5	17	0	21	42
3_IND	Oil Refineries	Hard Coal	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mgPM/Nm3	6	0,00	0,004	0,0	0,00	0,0	0,0	0,0	0,00	0,1	6397	1718	356	2363	1374	688	602	4113	64
			Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.	111		0,409									272							
		Heavy Fuel Oil	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20mgPM/Nm3	13	1,96	0,047	3,2	4,06	13,5	2,5	92,6	1,49	0,6	7	271	4	3	1	5	0	9	20
			Fuel switch from heavy fuel oil to natural gas	65	3,42	0,824	5,6	7,31	17,8	3,7	145,4	3,04	1,1	19	79	11	9	4	17	0	21	58

Table 22 Continued Source-sector specific costs, emission reduction and specific cost of emission reduction Cd, Pb, Hg and six other HM in 2020, for a possibly revised HM Protocol for UNECE-Europe, after full implementation of the 1998 HM Protocol.

					Avoided emission (tonnes)									Cost effectiveness (€ / g avoided emission)								
Sector	Sub-sector	Fuel type	Measure	Annual costs (M€)	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
3_IND	Coke Ovens	-	Control of fugitive emission from coke ovens by capturing and filtering, ELV = 50mgPM/Nm3	1241	2,58	0,149	11,1	0,98	17,6	6,7	4,5		11,6	482	8329	112	1261	70	184	278		107
3_IND	Iron & Steel, Blast furnaces	-	Addition of a fabric filter and evacuation to control fugitive emission from blast furnaces, ELV = 20mgPM/Nm3	84	0,87	0,100	213,2	6,25	5,3	38,7	10,8	1,48	627,9	97	847	0	13	16	2	8	57	0
3_IND	Iron & Steel, Electric Arc Furnace	-	Addition of fabric filters to control primary and secondary emission from electric arc furnaces, ELV = 15mgPM/Nm3	946	2,97	0,005	16,6	1,17	14,3	9,5	0,7	0,82	240,4	318	209561	57	810	66	100	1270	1150	4
3_IND	Iron & Steel, Oxygen Furnace	-	Addition of dry ESP or scrubber to control BOF primary emission, additional control of fugitive emission by fabric filters, ELV = 20mgPM/Nm3	527	1,62	0,018	94,4	0,91	6,8	6,5	3,2	0,16	246,6	326	28534	6	577	77	82	166	3333	2
3_IND	Iron & Steel, Sinter Production	-	Addition of fabric filters to sinter plant stacks, ELV = 20mgPM/Nm3	671	4,05	0,157	225,4	2,32	22,1	28,2	34,9	0,88	46,5	166	4285	3	289	30	24	19	760	14
3_IND	Primary Copper Production	-	Addition of fabric filters, wet ESP or ceramic filters to control stack emission from primary Cu smelters, ELV = 5mgPM/Nm3	234	16,40	0,022	79,3	41,00		235,3			434,8	14	10822	3	6		1			1
3_IND	Primary Lead Production	-	Addition of fabric filters to control stack emission from primary Pb smelters, ELV = 5mgPM/Nm3	60	1,46	0,178	162,5	0,97		3,6			25,8	41	339	0	62		17			2
3_IND	Primary Nickel Production	-	Addition of fabric filters to control stack emission from primary Ni smelters, ELV = 5mgPM/Nm3	36					301,3		117,9							0		0		
3_IND	Primary Zinc Production	-	Addition of fabric filters, scrubbers or ESP to control stack emission from primary Zn smelters, ELV = 5mgPM/Nm3	81	8,72	0,369	24,6						605,7	9	219	3						0
3_IND	Cement Production	-	Application of high performance ESP or FF to control primary emission from cement kilns	156	0,12	0,978	1,2	0,11	0,5		1,2	0,03	2,2	1294	159	126	1382	301		131	6218	72
		-	Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05mgHg/Nm3	2617		18,202									144							
3_IND	Chlorine Production	-	Reduction of Hg emission in Hg-based process, ELV = 0.5gHg/tonneCl2	1		1,969									1							
		-	Complete conversion from Hg-based to Hg-free process	29		2,626									11							
3_IND	Glass Production	-	Application of fabric filters or electrostatic precipitators in glass production, ELV = 30mgPM/Nm3	9	0,92	0,015	57,6	0,37	8,7	2,1	6,5	49,41	37,5	10	608	0	26	1	5	1	0	0
5_ROT	Road Transport (Exhaust)	-	Lowering the maximum allowable lead content of unleaded gasoline from 13 to 5 mg/l				1841,5															
7_WAS	Clinical Waste Incineration	-	Prededusting with ESP, lime and activated carbon injection followed by FF to control Hg emission from clinical waste incin., ELV = 0.05mgHg/Nm3	1		0,178									7							

4.8 Cost curves for further HM emission reduction

Another way of presenting specific costs are so called cost curves. In a cost curve, measures are sorted by ascending specific cost and plotted against the achieved emission reduction of that measure. This gives insight in how the specific costs develop when pursuing a higher degree of reduction. Separate cost curves are made for the two country groups EU(25)+ and the other, non-EU(25)+ UNECE Member States.

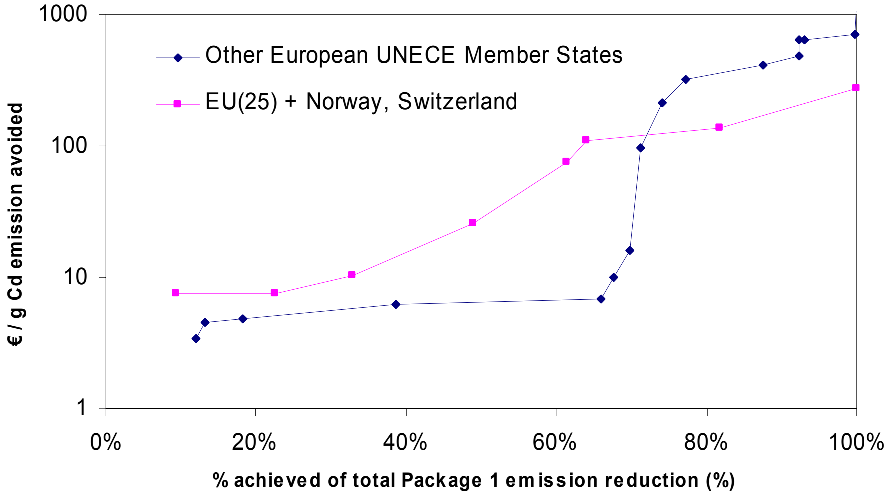

Figure 5 Specific cost of Cd reduction by Package 1 measures for 2 country groups.

The Cd cost curve (Figure 5) shows that initially emission reduction in the non-EU(25)+ countries appears cheaper until about 75% of the emission reduction potential is achieved. Then emission reduction in the EU(25)+ appears more attractive. It should be noted though that a significant part of the future emission reduction measures in the EU(25)+ are now assumed to fall under the EU IPPC Directive, which is regarded as autonomous policy in this study. The costs of implementing the IPPC Directive have therefore not been included in Figure 5 but these costs will still have to be made (but in this study not attributed to a possible revision of the HM Protocol).

Several more detailed observations can be made from Figure 5. For the EU(25)+ specific costs increase gradually, as can be expected almost as a straight line on a logarithmic scale, with a relatively narrow range. Emission of Cd appears to be reduced with almost all measures that combat HM emission in general. Applying end-of-pipe control techniques to residual oil-fired combustion plants is in both regions the most cost-effective way of reducing Cd emission. The next most cost-effective measures for the non-EU(25)+ are emission reduction measures in a number of industrial processes and in brown coal-firing in heat/powerplants. In the year 2020 and assuming full implementation of the 1998 HM Protocol, the only implemented set of ELVs besides national regulations for the non-EU countries is the 1998 HM Protocol. By contrast, in the EU(25) the more or equally stringent IPPC Directive will have entered into force as well. When disregarding the costs of the IPPC Directive, specific costs thus seem lower in the non-EU initially, suggesting a higher cost effectiveness. The picture changes when about 70% emission reduction is reached. After this point, measures taken for the EU(25)+ seem to be more cost efficient. However, the upper range for the non-EU(25)+ refers almost exclusively to relatively expensive measures for coal-fired power plants. This contrary to the EU plants, which are expected to comply with the proposed ELVs due to autonomous measures (implementation of EU Directives).

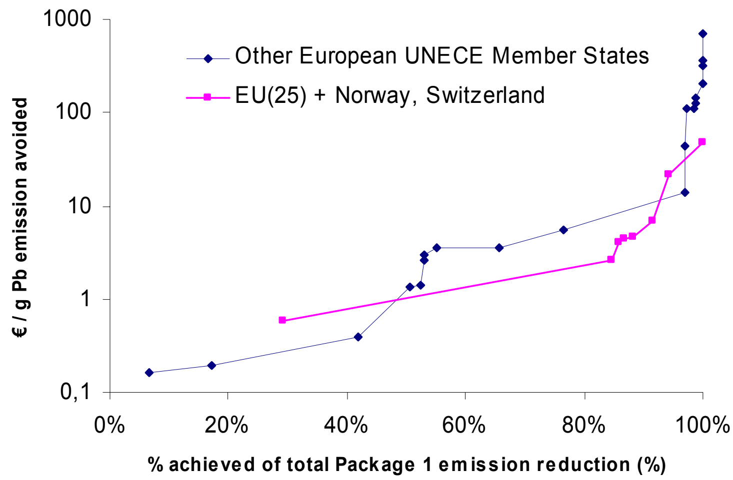

Figure 6 Specific cost of Pb reduction by Package 1 measures for 2 country groups.

The cost curves for Pb in the EU(25)+ and the non-EU(25) countries are shown in Figure 6. The emission reduction due to the lowering of the residual Pb content of gasoline is not included in this figure because of the uncertainty in the absolute emissions levels as well as that this measure is regarded as being cost-neutral (see section 3.16 for more details). The results for the two regions do not differ significantly. The specific costs for Pb show a wide range of almost 4 orders of magnitude. The most cost effective measures are those that specifically target Pb such as the abatement of emission from primary lead production. Pb reduction achieved by side-effects of other measures seems modest and relatively expensive.

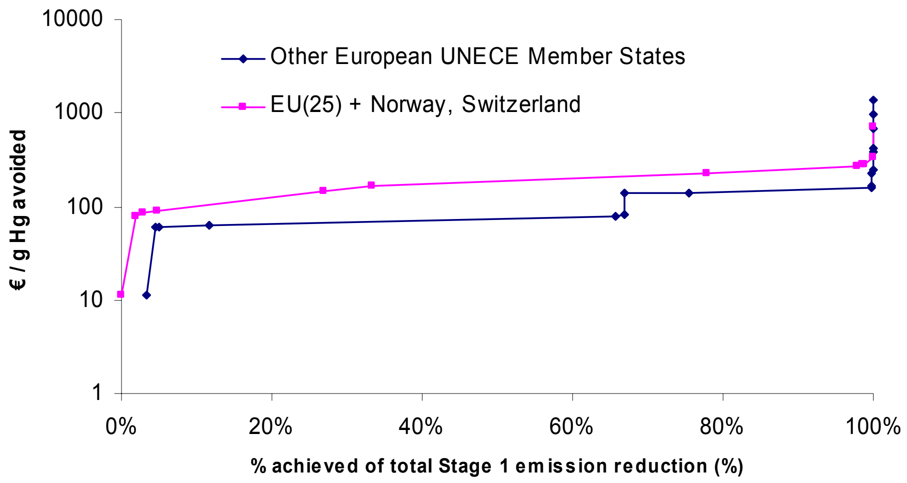

Figure 7 Specific cost of Hg reduction by Package 2 measures for 2 country groups.

The cost curve for Hg is shown in Figure 7, shows, as was also discussed in section 4.3.1, that the costs of all Package 2 measures are quite comparable and that the cost-efficiency is the same for both country groups. Apparently there is little difference in the degree of implementation as well as the remaining reduction potential of Hg measures in both regions. Package 2 measures specifically target Hg and this HM does not particularly benefit from side-effects of other measures, so specific costs are comparable for all countries. for most measures they are in the order of €100/g Hg avoided.

In figures 5-7 each step in the cost curve represents full implementation (all countries) of a specific measure. If we consider implementation country by country, a more 'fluid' relation is obtained (Figure 8). In Figure 8 the cost curves of all 9 HM that have been investigated in this study are depicted. In a cost curve the area below the curve represents the total costs for the whole considered domain. A more 'hollow' line (e.g. Ni, Cr, Zn) implies that only a relatively small number of countries will face high costs whereas a more convex shape (Hg, Cd) indicates relatively high costs for a larger number of countries. The cost curve for Pb in Figure 8 starts at about 60% of the achieved emission reduction. This is caused by our judgement that a further lowering of the Pb limit value of unleaded fuel and a phase-out of leaded fuel is achieved at no costs and/or is an autonomous measure. The cost curve for Pb emission reduction excluding road transport is depicted in Figure 6.

4.9 Concluding remark

The explicit aim throughout the study is to incorporate as much official data submissions by the countries to EMEP as possible. Hence the projected 2020 data are, as much as possible, a scaling of official year 2000 emission data to the projection year. TNO default estimates are only used to fill gaps in the base year inventory. The specific choice to use official country emission data complicates the assessment of emission reductions achieved and associated specific costs because the starting points for countries may not be comparable. For example, the implementation costs of a measure expressed per activity unit may be the same but the resulting emission reduction is dependent on the estimated emission in 2020 (which may differ depending on the official submitted data). As a result the specific costs (emission reduction divided by costs) may vary widely by country for the same measure. It is thought that the current study gives good insight in estimated emission and emission reduction potential and it is consistent with the earlier estimated emissions in 2000-2020. During the review of the HM Protocol, scheduled to take place after the entry into force of the Protocol, the results presented may be used to make a first assessment of the potential for further emission reduction and costs through possible revision of the Protocol. Should certain measures be considered to revise the current HM Protocol it is strongly advised to also make a full expert estimate of emissions, emission reductions and specific costs in individual countries. The result will not necessarily be a “better” approximation of the real-world emissions but it will give a more uniform and transparent assessment of costs and achieved emission reductions in a certain sector for all countries.

This report is the 2nd Phase of a larger study. The results of Phase I (Denier van der Gon et al., 2005) and Phase II (this study) illustrate that full implementation of the 1998 HM Protocol brings about the biggest step in reduction of HM emissions; a possible revision of the HM Protocol is a further improvement and should be seen in this perspective.

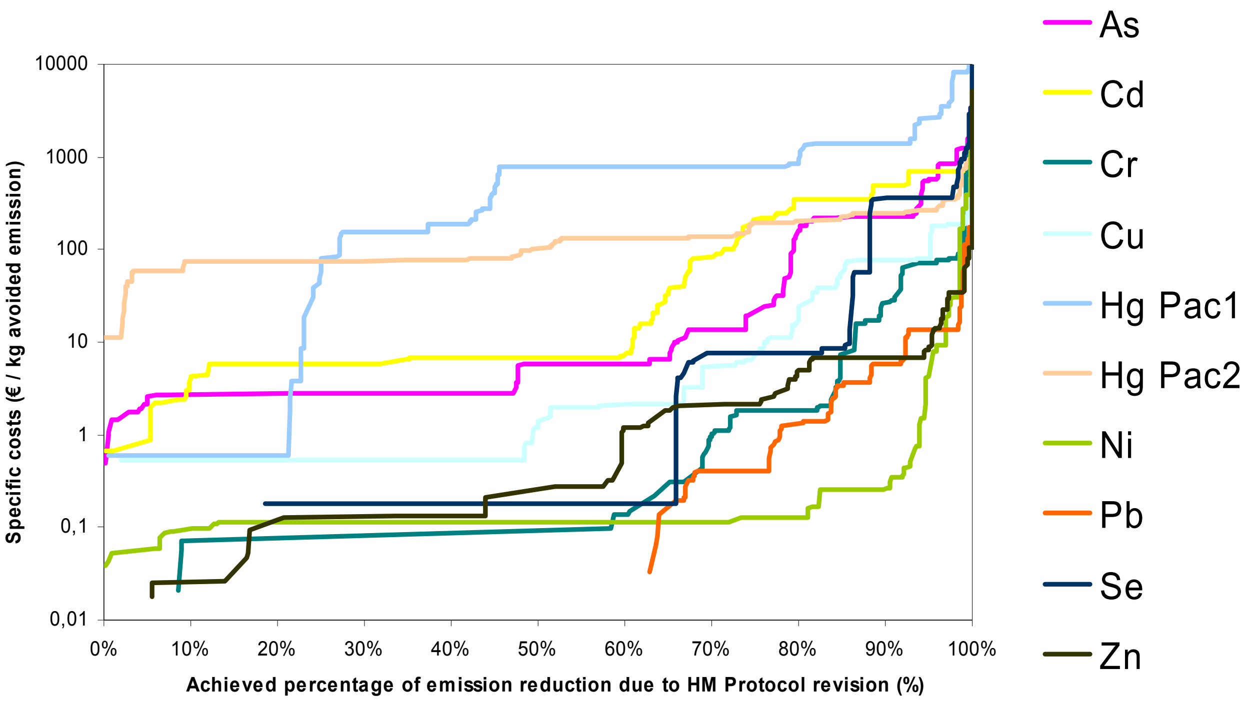

Figure 8 *The marginal costs of a revised HM Protocol for nine HM with step-wise implementation by country.*

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6. Authentication

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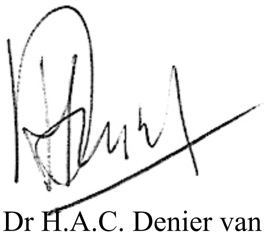
Names and establishments to which part of the research was put out to contract:

-

Date upon which, or period in which, the research took place:

November 2005 – July 2006

Signature:



Dr H.A.C. Denier van der Gon
Project leader

Approved by:

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Head of department

Annex 1 Keysource analysis of HM sources

Contribution of source categories to total HM emissions in 2020 after full implementation of HM Protocol and autonomeous measures

Source Category	Fuel	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Heat / Power Plants	Solid fuels	**8,3%**	**38,2%**	**6,7%**	**26,6%**	3,8%	14,8%	3,6%	**16,4%**	**18,3%**
	Liquid fuels	**9,8%**	2,1%	0,8%	5,1%	3,7%	1,1%	**32,3%**	5,1%	0,0%
	Gaseous fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Waste fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,8%
	Wood	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Oil Refineries	Solid fuels	0,0%	0,2%	0,0%	0,6%	0,3%	0,1%	0,1%	0,1%	0,1%
	Liquid fuels	1,7%	0,3%	0,1%	3,8%	1,1%	0,3%	6,7%	1,7%	0,0%
	Gaseous fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%
	Waste fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Solid Fuel Production	Solid fuels	0,4%	0,3%	0,2%	0,3%	0,2%	0,8%	0,1%	0,1%	0,2%
	Liquid fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Residential, commercial and other combustion	Solid fuels	**5,7%**	3,2%	2,5%	7,3%	3,1%	7,8%	5,1%	2,3%	5,2%
	Liquid fuels	**6,2%**	0,2%	0,9%	2,9%	0,5%	0,3%	4,3%	1,0%	0,1%
	Gaseous fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Waste fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Wood	3,5%	4,6%	1,1%	0,0%	1,5%	1,6%	0,5%	0,0%	2,2%
Industrial Combustion	Solid fuels	3,0%	**6,7%**	4,0%	9,8%	4,9%	4,1%	3,8%	3,2%	5,7%
	Liquid fuels	**7,2%**	1,1%	0,6%	6,9%	2,5%	0,8%	**17,6%**	3,5%	0,1%
	Gaseous fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Waste fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,9%
	Wood	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Coke Ovens	-	**6,8%**	2,5%	1,1%	1,4%	2,3%	1,0%	0,4%	0,0%	0,4%
Iron & Steel, Blast furnaces	-	1,6%	1,1%	**14,4%**	8,9%	2,3%	7,7%	1,4%	1,7%	**18,4%**
Iron & Steel, Sinter Production	-	4,5%	1,1%	**9,4%**	2,7%	4,0%	5,3%	3,7%	1,0%	1,4%
Iron & Steel, Pellet Production	-	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Iron & Steel, Oxygen Furnace	-	2,2%	0,2%	4,4%	0,9%	1,1%	0,7%	0,2%	0,1%	4,6%
Iron & Steel, Electric Arc Furnace	-	**9,4%**	0,1%	2,0%	1,6%	2,3%	1,8%	0,1%	1,2%	8,4%
Iron & Steel, Open Hearth Furnace	-	0,0%	0,0%	0,0%	0,0%	0,0%	2,3%	0,0%	0,0%	0,0%
Iron & Steel, Foundries	-	0,4%	0,1%	0,5%	0,6%	0,4%	0,3%	0,1%	0,0%	0,3%
Soederberg Aluminium	-	0,4%	0,0%	0,0%	0,0%	0,0%	0,0%	0,9%	0,0%	0,2%
Pre-baked Aluminium	-	0,4%	0,0%	0,0%	0,0%	0,0%	0,0%	1,0%	0,0%	0,2%
Primary Copper Production	-	**10,7%**	0,1%	1,9%	13,8%	0,0%	**18,6%**	0,0%	0,0%	4,5%
Secondary Copper Production	-	1,0%	0,0%	0,9%	0,5%	0,0%	0,7%	0,0%	0,0%	1,3%
Primary Lead Production	-	1,4%	1,1%	**5,6%**	0,3%	0,0%	0,2%	0,0%	0,0%	0,2%
Secondary Lead Production	-	1,1%	0,0%	2,6%	3,0%	0,0%	0,0%	0,0%	0,0%	1,0%
Primary Zinc Production	-	**5,4%**	1,6%	0,6%	0,0%	0,0%	0,0%	0,0%	0,0%	12,5%
Primary Nickel Production	-	0,0%	0,0%	0,0%	0,0%	**61,3%**	0,0%	14,0%	0,0%	0,0%
Primary Mercury Production	-	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Primary gold production	-	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Source Category	Fuel	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Chlorine Production	-	0,0%	0,8%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Cement Production	-	1,3%	**28,8%**	0,6%	1,4%	0,9%	0,0%	0,7%	0,2%	0,5%
Glass Production	-	0,9%	0,3%	2,1%	0,9%	1,7%	0,5%	0,6%	**61,3%**	1,4%
Oil and Gas Extraction	Liq. & gas. fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Road Transport (Abrasion)	Gasoline	0,6%	0,0%		0,0%	0,1%	0,8%	0,1%	0,0%	1,9%
	Diesel	1,0%	0,0%	0,0%	0,0%	0,1%	0,5%	0,1%	0,0%	1,8%
	Gaseous fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Road Transport (Exhaust)	Gasoline	1,3%	0,0%	**33,8%**	0,0%	0,3%	7,3%	0,4%	0,3%	1,0%
	Diesel	1,3%	0,0%	0,0%	0,0%	0,3%	7,5%	0,3%	0,3%	0,6%
	Gaseous fuels	0,0%	0,0%	0	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Domestic Air Transport	Gasoline	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Kerosines	0,1%	0,0%	0,0%	0,0%	0,0%	0,4%	0,1%	0,0%	0,1%
Internal Navigation	Diesel	0,0%	0,1%	0,0%	0,0%	0,0%	0,0%	0,2%	0,2%	0,0%
	Gasoline	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Heavy Fuel Oil	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%	0,9%	0,1%	0,0%
	Kerosines	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Non-specified Transport	Diesel	0,0%	0,0%	0,2%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Gasoline	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Heavy Fuel Oil	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%
	Kerosines	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Rail Transport	-	0,0%	0,0%	0,0%	0,0%	0,0%	10,6%	0,0%	0,0%	0,0%
	Solid fuels	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Diesel	0,1%	0,0%	1,7%	0,1%	0,0%	0,4%	0,1%	0,0%	0,0%
	Kerosines	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	Heavy fuel oil	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%
Municipal Waste Incineration	-	1,4%	1,3%	1,0%	0,3%	0,7%	0,8%	0,2%	0,1%	2,1%
Industrial Waste Incineration	-	0,4%	2,9%	0,1%	0,1%	0,2%	0,3%	0,1%	0,0%	0,7%
Hazardous Waste Incineration	-	0,3%	0,6%	0,2%	0,1%	0,2%	0,2%	0,1%	0,0%	0,6%
Clinical Waste Incineration	-	0,1%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Cremation	-	0,0%	0,3%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Other Sources	-	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Unidentified Source	-	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
Selected measures		**72%**	**85%**	**83%**	**79%**	**90%**	**63%**	**79%**	**94%**	**73%**
addtional Pb		2%	0%	4%	1%	1%	1%	0%	0%	5%
Residential / domestic sources		16%	8%	5%	10%	5%	11%	10%	3%	8%
Selected + residential		90%	93%	93%	91%	96%	75%	89%	97%	85%

Annex 2 Emission after a possible revision of the HM Protocol, associated emission reduction and costs by country available on CD-ROM inserted in back cover of the report

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ADDENDUM to 2006-A-R0087/B

Study to the effectiveness of the UNECE Heavy Metals (HM) Protocol and cost of additional measures

Phase II: Estimated emission reduction and cost of options for a possible revision of the HM Protocol

Date
July 2006

Authors
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This addendum summarizes the results of the possible revision of the HM protocol as outlined in TNO Report 2006-A-R0087/B by individual country. The basis for calculation of potential emission reductions upon possible revision of the UNECE HM protocol are the remaining Heavy Metal (HM) emissions upon full implementation of the 1998 HM Protocol and other autonomous measures estimated by Denier van der Gon et al. (2005) and presented in TNO Report 2006-A-R0087/B as Table 3. This Table is reproduced for convenience in this addendum as Table Ad.1.

The emission reduction and associated costs due to implementation of Package 1 measures by country are presented in Table Ad.2. The projected corresponding remaining HM emissions in 2020 after implementation of Package 1 are presented in Table Ad.3. The emission reduction and associated costs due to implementation of Package 2 by country are presented in Table Ad.4. The projected corresponding remaining HM emissions in 2020 after implementation of Package 2 are presented in Table Ad.5. The emission reduction and associated costs due to implementation of Package 1+2 by country are presented in Table Ad.6. The projected corresponding remaining HM emissions in 2020 after implementation of Package 1+2 are presented in Table Ad.7. The Package 1 and Package 2 measures are abbreviated in Tables Ad.2-Ad.7, a legend to the abbreviations used is presented in table Ad. 8.

The tables presented in this addendum give a comprehensive overview of the emission reductions and remaining emissions after a possible revision of the 1998 HM protocol and facilitate an assessment on a national scale. The totals as given in the Tables A2-A7 correspond with the totals given for UNECE-Europe in the summary and conclusions chapter of TNO Report 2006-A-R0087/B. For a more detailed breakdown of the projected emission reductions by country, we refer to the folder *Annex 2 Country data* on the CD-ROM accompanying TNO Report 2006-A-R0087/B.

The measures considered for a possible revision of the HM protocol in this study are separated in a Package I and Package II proposal. Package 1 focuses on (further) dust removal, the more traditional way to reduce emissions of HM. The Package 2 proposal specifically addresses (gaseous) Hg emissions that are poorly mitigated by the tightening of the dust ELVs outlined in Package 1. In general Package 2 measures are more expensive. However, in some cases (e.g. a proposed fuel switch from fuel oil to gas) the Package 2 measure will make the Package 1 measure for a particular source redundant. The costs for implementing Package 1+2 for two different country groups (EU25+ and Non-EU25+), associated emission reduction and projected remaining HM emission after implementing Package 1+2 are presented in table Ad.9 and Ad.10, respectively. For a discussion on the difference between the costs for the two country groups we refer to the main report, section 4.3.

The first phase of the present study was published in August 2005 “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). After publication of the report an error in the projected Pb emissions for a few countries was discovered. The 2005 phase I report and an erratum dated July 2006 to TNO report B&O-A R 2005/193 are included on the CD-ROM accompanying TNO Report 2006-A-R0087/B.

Table Ad.1*:
Projected annual emissions of heavy metals in UNECE-Europe by country in 2020 following IIASA CLE-BL scenario and assuming all UNECE countries implement the HM Protocol before 2010.

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Albania	190	193	6083	155	493	1626	5476	117	4232
Armenia	142	194	1142	103	403	685	4160	154	2618
Austria	1432	1210	14816	2821	9741	38417	25833	1481	250095
Azerbaijan	2702	1153	16654	2684	6718	6134	119717	2377	18863
Belarus	906	400	38806	2616	3832	10155	99190	5344	59330
Belgium	1583	1460	78203	1490	9554	21132	23849	2114	115617
Bosnia-Herzegovina	602	1552	15576	577	509	3762	4651	314	19496
Bulgaria	4244	3587	68043	1011	2938	9474	13126	11644	40743
Croatia	601	375	8260	379	2525	11743	10995	400	88800
Cyprus	725	778	6251	718	1829	2104	31251	615	2751
Czech Republic	991	2357	11169	2348	4306	22016	14703	4256	104580
Denmark	701	1837	5861	470	3311	12223	5852	1056	67626
Estonia	198	344	14203	1920	1786	2216	2902	323	12579
Finland	1394	526	38300	4495	15305	21975	16711	3711	79833
France	7859	14194	179014	20444	160292	188634	158743	8530	1549390
Georgia	262	305	10181	211	676	3692	7447	150	4613
Germany	21571	40234	647079	33587	61685	328887	114784	21643	1982015
Greece	2249	7004	8485	2216	14814	18720	66532	1311	79500
Hungary	2563	3033	33897	2698	2879	20890	18702	475	38688
Iceland	84	87	172	73	176	464	3747	44	2862
Ireland	764	1351	6478	722	1478	10199	15380	497	30653
Italy	6607	8931	812905	25773	19331	48247	38763	34293	973348
Kazakhstan	14410	17051	416719	30134	22918	144317	74780	6455	624659
Kyrgyzstan	307	672	8272	286	844	1941	4277	224	10822
Latvia	366	453	1109	671	4849	2616	8935	393	18876
Lithuania	1488	620	28357	811	2041	12995	14433	905	134915
Luxembourg	57	293	4018	53	247	1618	390	27	46163
Macedonia	4582	1664	28340	345	473	2182	3635	96	206665
Netherlands	1174	412	38059	960	5848	14871	49462	1178	124380
Norway	975	1202	7539	2291	5405	24005	36564	516	83343
Poland	20627	21361	224645	16508	31115	105133	86464	19498	794350
Portugal	2472	6655	20501	2515	7890	23267	63073	15152	113789
Republic of Moldova	324	131	3266	239	489	1569	5488	1654	8268
Romania	4432	9115	101278	2058	5495	20874	56505	7896	144271
Russia	62518	86531	1558887	82677	360816	582690	1019824	60986	2556553
Slovak Republic	3168	3700	27542	3156	2482	11284	10698	2655	29310
Slovenia	1415	584	12866	304	649	4040	3543	191	15031
Spain	6850	13837	163870	18488	15315	113689	24468	23936	700703
Sweden	329	1257	13713	879	4891	17405	11335	911	299756
Switzerland	3037	2271	122507	750	3702	21674	6789	301	680738
Turkey	9804	25524	314476	9864	25499	87969	168846	27882	398530
Ukraine	12698	21592	500061	17682	48477	113189	105073	11688	909508
United Kingdom	4691	5290	100605	17929	24574	18685	54241	8845	287168
Yugoslavia	2623	4659	42894	2026	1735	16556	10380	2220	49491
Total (tonnes)	***217***	***316***	***5761***	***318***	***900***	***2126***	***2622***	***294***	***13766***

* This Table is included in the report as Table 3, reproduced here for convenience only.

Table Ad.2:
National emission reduction (kg/yr) and costs due to a possible revision of the HM Protocol following Package 1 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Costs (M€)
Albania	19	4	5052	24	51	60	820	13	107	2
Armenia	1	3	630	0	8	1	8	44	29	0
Austria	161	4	1716	215	2878	1843	8757	141	4760	31
Azerbaijan	1516	101	11050	1563	4814	1623	80183	1234	335	9
Belarus	230	12	16871	733	2121	1776	62105	3044	14607	20
Belgium	624	21	31363	188	1882	835	9986	326	29692	90
Bosnia-Herzegovina	158	76	11604	250	125	713	1462	138	6961	68
Bulgaria	1682	138	45151	475	1694	1716	5753	6921	17935	185
Croatia	103	4	1144	127	1166	228	5131	148	1530	5
Cyprus	360	18	5269	371	1204	406	19015	283	74	2
Czech Republic	103	6	937	102	531	390	4654	75	884	15
Denmark	27	1	127	8	30	23	564	3	407	8
Estonia	35	0	6524	195	643	21	1258	11	17	0
Finland	361	2	4796	1072	10255	7244	8695	84	6789	34
France	1533	45	34312	2195	63924	2548	61967	994	64546	170
Georgia	78	7	8748	82	248	87	4113	62	64	1
Germany	3410	125	123292	2768	7156	32272	28972	585	80966	296
Greece	552	22	1106	521	9868	766	29107	400	2976	19
Hungary	145	7	26741	335	500	261	2878	43	378	10
Iceland	2	2	17	14	44	4	163	8	33	2
Ireland	106	4	234	90	298	102	4597	72	966	5
Italy	1967	59	706580	3057	6923	4355	8707	731	268801	175
Kazakhstan	7375	653	185115	16431	3131	79274	30095	1763	259468	570
Kyrgyzstan	13	16	4828	40	13	113	30	53	1273	9
Latvia	102	3	122	149	1585	107	4967	98	1422	0
Lithuania	58	2	22985	45	161	92	1790	48	48	0
Luxembourg	5	0	471	1	42	87	4	2	6587	26
Macedonia	3271	100	18454	171	212	600	1967	38	152465	40
Netherlands	284	1	6468	52	658	558	9959	79	6680	30
Norway	172	1	1012	357	2892	2888	15282	39	9816	22
Poland	1343	41	20607	1255	3466	12496	15804	210	33839	78
Portugal	510	21	1388	485	2117	718	24355	371	2332	16
Republic of Moldova	39	6	2567	18	163	22	2449	981	1310	9
Romania	2610	1868	78189	1053	3393	2676	34671	4586	88384	222
Russia	28959	4066	1004465	43442	278544	180098	592694	30317	1096085	4050
Slovak Republic	306	8	5775	97	378	605	1017	32	504	12
Slovenia	92	1	7342	27	185	69	1251	21	672	6
Spain	993	9	13847	1683	4176	8523	778	343	64828	166
Sweden	63	6	4076	103	1574	1457	4367	27	5286	39
Switzerland	199	2	10989	46	190	111	2268	42	8064	10
Turkey	2990	821	227690	3484	7963	14452	52722	14841	87454	901
Ukraine	3199	718	218372	4970	15103	26080	25392	3989	338950	1260
United Kingdom	756	38	36295	1458	15428	2543	20162	334	13865	81
Yugoslavia	1170	247	34356	1153	617	5634	3452	1260	21836	284
Total (tonnes)	***68***	***9***	***2949***	***91***	***458***	***396***	***1194***	***75***	***2704***	***8981***

Table Ad.3: National emissions (kg/yr) after a possible revision of the HM Protocol following Package 1 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Albania	171	190	1031	131	442	1566	4656	104	4125
Armenia	141	191	512	103	395	683	4153	109	2589
Austria	1271	1207	13099	2605	6863	36574	17076	1341	245334
Azerbaijan	1186	1052	5604	1121	1905	4511	39534	1143	18528
Belarus	677	388	21935	1883	1711	8379	37085	2300	44723
Belgium	959	1439	46839	1302	7672	20297	13864	1788	85925
Bosnia-Herzegovina	444	1476	3972	327	384	3050	3188	176	12535
Bulgaria	2562	3450	22892	536	1245	7758	7373	4722	22808
Croatia	497	370	7116	252	1359	11515	5864	252	87269
Cyprus	366	760	983	347	625	1698	12236	331	2677
Czech Republic	888	2352	10231	2246	3775	21626	10049	4182	103696
Denmark	674	1836	5734	462	3281	12200	5287	1053	67219
Estonia	163	344	7680	1724	1143	2195	1644	311	12562
Finland	1033	524	33504	3423	5049	14732	8016	3628	73044
France	6327	14149	144702	18250	96368	186086	96777	7536	1484845
Georgia	184	298	1434	130	428	3605	3334	88	4549
Germany	18161	40109	523787	30819	54529	296615	85813	21058	1901049
Greece	1697	6983	7379	1694	4946	17953	37425	911	76524
Hungary	2418	3026	7156	2364	2380	20629	15824	432	38310
Iceland	82	84	154	59	132	460	3584	37	2829
Ireland	657	1347	6244	632	1179	10097	10783	424	29687
Italy	4640	8871	106325	22717	12407	43892	30057	33562	704546
Kazakhstan	7035	16398	231604	13703	19788	65043	44685	4692	365191
Kyrgyzstan	294	656	3444	246	831	1828	4247	171	9549
Latvia	265	450	987	523	3264	2509	3969	296	17454
Lithuania	1430	617	5372	766	1880	12903	12643	857	134868
Luxembourg	53	293	3547	52	204	1531	386	25	39576
Macedonia	1311	1565	9887	173	260	1583	1668	57	54200
Netherlands	890	411	31591	909	5189	14313	39503	1099	117701
Norway	803	1201	6527	1934	2514	21117	21282	477	73527
Poland	19284	21320	204038	15253	27649	92637	70660	19288	760511
Portugal	1962	6634	19113	2030	5773	22549	38718	14781	111457
Republic of Moldova	284	125	699	221	326	1547	3039	673	6958
Romania	1822	7247	23090	1005	2101	18199	21834	3310	55887
Russia	33559	82465	554422	39235	82272	402592	427131	30669	1460467
Slovak Republic	2862	3692	21767	3059	2104	10679	9681	2623	28806
Slovenia	1323	583	5524	277	464	3972	2292	170	14359
Spain	5858	13828	150023	16805	11139	105166	23690	23593	635875
Sweden	266	1250	9637	776	3317	15948	6969	885	294470
Switzerland	2838	2268	111517	704	3511	21564	4521	260	672674
Turkey	6814	24703	86787	6380	17536	73517	116124	13041	311076
Ukraine	9499	20874	281689	12712	33374	87109	79681	7699	570558
United Kingdom	3935	5252	64310	16471	9146	16142	34079	8510	273303
Yugoslavia	1453	4413	8538	873	1118	10922	6928	960	27655
Total (tonnes)	***149***	***307***	***2812***	***227***	***442***	***1729***	***1427***	***220***	***11061***

Table Ad.4:
National emission reduction (kg/yr) and costs due to a possible revision of the HM Protocol following Package 2 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Costs (M€)
Albania	24	27	42	25	60	23	1150	22	5	4
Armenia	0	13	0	0	0	0	0	0	0	2
Austria	96	403	103	221	525	204	10102	195	43	116
Azerbaijan	2389	839	4126	2476	5864	2280	112930	2178	478	48
Belarus	236	97	2006	977	1358	1069	86825	905	168	36
Belgium	81	389	318	158	1315	156	15226	491	16	148
Bosnia-Herzegovina	40	1021	68	41	97	38	1874	36	8	93
Bulgaria	1068	1536	1052	140	332	129	6388	123	27	241
Croatia	138	144	139	194	911	183	7825	161	21	53
Cyprus	654	339	307	678	1605	624	30919	596	131	29
Czech Republic	93	505	51	151	358	139	6886	133	29	467
Denmark	15	499	25	14	31	23	916	4	2	77
Estonia	64	263	820	357	857	32	2046	24	28	66
Finland	96	255	127	273	101	160	2958	113	15	197
France	1642	7600	3326	3421	21522	1704	90705	1700	1687	747
Georgia	122	65	211	127	300	117	5787	112	24	6
Germany	627	15634	1082	649	1538	598	29625	571	125	3262
Greece	898	2865	1551	930	2204	857	42444	819	180	571
Hungary	201	1047	166	530	451	145	4579	88	14	202
Iceland	3	24	5	3	7	3	136	3	1	3
Ireland	158	422	273	164	388	151	7474	144	32	83
Italy	523	2180	1548	4381	4449	1874	13650	1301	356	791
Kazakhstan	812	8123	1402	841	1992	775	38365	740	162	624
Kyrgyzstan	0	176	0	0	0	0	0	0	0	15
Latvia	185	325	221	271	2099	164	8076	206	1363	31
Lithuania	105	154	183	83	215	141	2911	101	84	72
Luxembourg	0	83	0	0	0	0	1	0	0	10
Macedonia	54	434	93	56	132	51	2547	49	11	52
Netherlands	65	99	99	42	157	40	10528	95	11	101
Norway	50	455	160	204	16	175	3498	67	15	41
Poland	1094	10052	1660	1108	1814	1649	24212	376	298	1891
Portugal	834	2006	1441	865	2048	796	39446	761	167	268
Republic of Moldova	52	81	6	17	183	11	3223	21	5	4
Romania	999	4521	1725	1035	2451	953	47207	911	200	328
Russia	14447	45339	24953	14972	35460	13790	682926	13173	2889	4110
Slovak Republic	4	633	8	59	196	23	557	20	1	182
Slovenia	128	271	104	44	105	41	2022	39	9	59
Spain	0	2635	0	0	0	0	0	0	0	274
Sweden	50	671	283	82	1230	226	6594	52	48	220
Switzerland	171	308	1304	78	186	72	3577	69	61	36
Turkey	1453	7236	2509	1505	3566	1387	68671	1325	291	1350
Ukraine	408	7305	704	423	1001	389	19276	372	82	575
United Kingdom	711	1252	1502	1977	2931	2175	21257	683	120	689
Yugoslavia	86	2917	149	89	211	82	4066	78	17	384
Total (tonnes)	***31***	***131***	***56***	***40***	***100***	***33***	***1469***	***29***	***9***	***18560***

Table Ad.5: National emissions (kg/yr) after a possible revision of the HM Protocol following Package 2 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Albania	165	166	6041	130	433	1603	4326	95	4227
Armenia	142	181	1142	103	403	685	4160	154	2618
Austria	1336	807	14713	2599	9217	38213	15731	1287	250052
Azerbaijan	313	314	12527	208	855	3854	6787	199	18385
Belarus	671	304	36800	1639	2474	9086	12365	4439	59163
Belgium	1502	1071	77884	1332	8239	20976	8623	1622	115601
Bosnia-Herzegovina	563	531	15507	536	412	3724	2777	278	19488
Bulgaria	3176	2051	66991	871	2607	9345	6738	11520	40716
Croatia	463	230	8121	185	1614	11560	3170	238	88779
Cyprus	71	439	5945	40	223	1479	332	18	2620
Czech Republic	899	1853	11118	2197	3948	21877	7817	4124	104551
Denmark	687	1338	5836	456	3280	12199	4935	1052	67625
Estonia	134	81	13383	1563	929	2183	856	299	12550
Finland	1298	271	38173	4222	15204	21815	13752	3598	79818
France	6217	6593	175688	17023	138770	186930	68038	6830	1547704
Georgia	140	240	9970	84	376	3575	1660	38	4588
Germany	20945	24600	645996	32937	60147	328288	85159	21072	1981890
Greece	1351	4139	6934	1285	12610	17863	24088	492	79321
Hungary	2362	1986	33731	2169	2428	20745	14123	387	38674
Iceland	81	63	167	70	169	461	3611	42	2862
Ireland	606	929	6205	558	1090	10048	7906	352	30621
Italy	6084	6751	811358	21392	14881	46372	25113	32991	972992
Kazakhstan	13598	8929	415318	29293	20926	143542	36415	5715	624496
Kyrgyzstan	307	496	8272	286	844	1941	4277	224	10822
Latvia	182	128	888	400	2750	2452	860	188	17513
Lithuania	1383	466	28175	728	1826	12853	11522	804	134831
Luxembourg	57	210	4018	53	247	1618	388	27	46163
Macedonia	4528	1231	28247	289	340	2131	1088	46	206654
Netherlands	1109	313	37960	918	5691	14831	38934	1083	124370
Norway	925	747	7379	2087	5390	23829	33066	449	83328
Poland	19533	11309	222985	15401	29301	103484	62252	19122	794052
Portugal	1638	4648	19060	1650	5842	22470	23627	14392	113622
Republic of Moldova	272	50	3260	223	306	1558	2265	1632	8264
Romania	3433	4594	99554	1023	3043	19921	9298	6986	144071
Russia	48071	41192	1533934	67705	325356	568900	336898	47813	2553663
Slovak Republic	3164	3068	27534	3097	2285	11261	10141	2635	29309
Slovenia	1287	313	12762	259	544	3999	1521	152	15023
Spain	6850	11202	163870	18488	15315	113689	24468	23936	700703
Sweden	279	586	13430	797	3661	17179	4742	860	299708
Switzerland	2866	1963	121203	672	3516	21602	3212	232	680677
Turkey	8351	18288	311967	8359	21933	86582	100175	26558	398239
Ukraine	12290	14287	499357	17260	47476	112800	85797	11316	909426
United Kingdom	3980	4038	99103	15952	21642	16510	32984	8162	287047
Yugoslavia	2537	1743	42746	1937	1524	16474	6314	2141	49474
Total (tonnes)	***186***	***185***	***5705***	***278***	***800***	***2093***	***1152***	***266***	***13756***

Table Ad.6:
National emission reduction (kg/yr) and costs due to a possible revision of the HM Protocol following Package 1+2 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Costs (M€)
Albania	28	28	5067	34	62	67	1154	23	108	5
Armenia	1	14	630	0	8	1	8	44	29	2
Austria	204	405	1762	316	3009	1914	12646	243	4779	146
Azerbaijan	2389	842	12558	2476	5871	2282	112937	2219	505	48
Belarus	316	98	17604	1094	2366	2084	87288	3453	14667	52
Belgium	661	409	31506	259	2210	890	15848	584	29699	237
Bosnia-Herzegovina	172	1022	11629	265	143	723	2006	155	6963	161
Bulgaria	2073	1546	45535	526	1753	1753	7606	6977	17945	426
Croatia	165	144	1206	215	1393	292	8144	233	1539	58
Cyprus	654	339	5407	678	1605	624	30919	596	131	29
Czech Republic	145	509	960	170	621	439	7305	144	896	482
Denmark	33	501	139	15	38	31	917	5	408	85
Estonia	64	263	6893	357	857	32	2046	24	30	66
Finland	404	256	4854	1195	10281	7299	9834	143	6796	231
France	2271	7622	35808	3744	69305	3145	96888	1887	65280	911
Georgia	123	66	8825	128	302	121	5791	113	73	6
Germany	3692	15748	123779	3062	7541	32481	40377	885	81021	3556
Greece	956	2871	1804	943	10419	1066	45448	830	3054	586
Hungary	236	1050	26816	574	612	312	4641	89	385	211
Iceland	3	24	19	15	45	5	203	9	33	5
Ireland	177	423	356	164	395	155	7474	148	980	88
Italy	2202	2223	707277	5040	8036	5011	13962	1414	268956	955
Kazakhstan	7672	8186	185628	16741	3490	79498	41222	2097	259526	1191
Kyrgyzstan	13	178	4828	40	13	113	30	53	1273	24
Latvia	185	325	221	271	2110	164	8076	206	2015	31
Lithuania	105	155	23067	83	215	141	2911	101	84	72
Luxembourg	5	83	471	1	42	87	4	2	6587	36
Macedonia	3291	498	18488	192	236	615	2706	60	152469	92
Netherlands	313	100	6513	71	698	572	14012	129	6684	130
Norway	194	455	1084	449	2895	2949	16628	74	9823	63
Poland	1835	10083	21354	1757	3920	13074	25125	407	33969	1968
Portugal	885	2012	2036	877	2629	997	39541	771	2404	280
Republic of Moldova	59	81	2570	24	196	25	3384	990	1312	13
Romania	2975	4640	78819	1435	3836	2951	48363	4998	88455	545
Russia	34239	45753	1013585	48961	284940	184078	790769	36271	1097118	8105
Slovak Republic	308	641	5779	123	427	613	1231	42	505	194
Slovenia	150	271	7388	47	211	83	2029	42	676	65
Spain	993	2644	13847	1683	4176	8523	778	343	64828	440
Sweden	86	674	4203	140	1882	1536	6905	54	5307	258
Switzerland	276	309	11576	82	237	136	3645	78	8091	47
Turkey	3521	7276	228607	4039	8606	14852	72639	15440	87558	2246
Ukraine	3348	7459	218630	5126	15284	26192	30983	4157	338979	1833
United Kingdom	1076	1283	36971	2353	16160	3304	28346	693	13918	768
Yugoslavia	1202	2922	34411	1186	655	5658	4631	1295	21842	667
Total (tonnes)	***80***	***132***	***2971***	***107***	***480***	***407***	***1657***	***89***	***2708***	***27417***

Table Ad.7: National emissions (kg/yr) after a possible revision of the HM Protocol following Package 1+2 in 2020

Country	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Albania	162	165	1016	121	431	1559	4322	94	4123
Armenia	141	180	512	103	395	683	4153	109	2589
Austria	1228	805	13053	2505	6732	36503	13186	1239	245316
Azerbaijan	313	311	4096	208	847	3853	6780	158	18357
Belarus	591	302	21202	1523	1466	8071	11902	1891	44663
Belgium	922	1051	46696	1231	7343	20242	8002	1530	85918
Bosnia-Herzegovina	430	530	3947	312	367	3039	2645	160	12532
Bulgaria	2172	2041	22508	485	1185	7721	5520	4667	22798
Croatia	435	230	7053	164	1131	11451	2851	167	87260
Cyprus	71	438	845	40	223	1479	332	18	2620
Czech Republic	846	1848	10208	2178	3685	21577	7398	4112	103683
Denmark	668	1336	5723	455	3273	12192	4935	1051	67219
Estonia	134	81	7311	1563	929	2183	856	299	12549
Finland	990	270	33447	3300	5024	14676	6877	3568	73037
France	5588	6571	143205	16701	90987	185490	61855	6643	1484111
Georgia	139	239	1356	83	374	3571	1656	38	4540
Germany	17879	24486	523300	30525	54144	296405	74407	20758	1900995
Greece	1293	4133	6681	1273	4395	17653	21085	481	76446
Hungary	2328	1983	7081	2124	2267	20578	14061	386	38303
Iceland	81	63	153	58	131	459	3544	36	2829
Ireland	586	928	6122	558	1082	10044	7905	349	29674
Italy	4405	6708	105629	20733	11295	43236	24801	32878	704392
Kazakhstan	6738	8865	231092	13393	19428	64819	33557	4358	365133
Kyrgyzstan	294	494	3444	246	831	1828	4247	171	9549
Latvia	182	128	888	400	2739	2452	860	188	16861
Lithuania	1383	465	5290	728	1826	12853	11522	804	134831
Luxembourg	53	210	3547	52	204	1531	385	25	39576
Macedonia	1291	1166	9853	153	236	1568	929	35	54196
Netherlands	861	312	31547	890	5150	14299	35450	1049	117696
Norway	781	746	6455	1841	2510	21056	19936	442	73520
Poland	18792	11278	203291	14752	27195	92060	61339	19090	760381
Portugal	1587	4642	18465	1638	5261	22270	23532	14382	111384
Republic of Moldova	265	50	696	215	293	1544	2104	663	6957
Romania	1457	4475	22460	624	1659	17923	8142	2899	55815
Russia	28279	40779	545302	33715	75876	398612	229055	24715	1459434
Slovak Republic	2860	3060	21763	3032	2054	10671	9467	2613	28805
Slovenia	1265	312	5477	256	438	3957	1514	149	14355
Spain	5858	11193	150023	16805	11139	105166	23690	23593	635875
Sweden	243	582	9510	739	3010	15869	4430	858	294449
Switzerland	2761	1962	110931	668	3465	21538	3144	224	672647
Turkey	6283	18248	85869	5825	16893	73117	96207	12442	310972
Ukraine	9350	14134	281431	12556	33193	86997	74090	7531	570528
United Kingdom	3615	4006	63634	15576	8413	15381	25895	8152	273250
Yugoslavia	1422	1738	8484	840	1080	10898	5749	924	27649
Total (tonnes)	**137**	**184**	**2791**	**211**	**421**	**1719**	**964**	**206**	**11058**

Table Ad. 8: Legend of abbreviations for Package 1 measures and Package 2 measures suggested for a possible revision of the HM Protocol.

Package 1 Measure	Description of Stage 1 Measure	Package 2 Measure	Description of Stage 2 Measure
S1-1	Addition of electrostatic precipitators to heavy oil-fired large combustion plants, ELV = 20mg PM/Nm^3	S2-1	Fuel switch from heavy fuel oil to natural gas
S1-2	Addition of fabric filters to coal-fired large combustion plants, ELV = 20mg PM/Nm^3	S2-2	Specific removal of Hg from coal-fired large combustion plants by injection of activated carbon, 80% rem. eff.
S1-3	Addition of fabric filters to control primary and secondary emission from electric arc furnaces, ELV = 15mg PM/Nm^3	S2-3	Specific removal of Hg from cement ovens by injection of activated carbon, ELV = 0.05mg Hg/Nm^3
S1-4	Addition of fabric filters, wet ESP or ceramic filters to control stack emission from primary Cu smelters, ELV = 5mg PM/Nm^3	S2-4	Complete conversion from Hg-based to Hg-free process
S1-5	Addition of fabric filters to control stack emission from primary Ni smelters, ELV = 5mgPM/Nm^3		
S1-6	Application of high performance ESP or FF to control primary emission from cement kilns		
S1-7	Lowering the maximum allowable lead content of unleaded gasoline from 13 to 5 mg/l		
S1-8	Prededusting with ESP, lime and activated carbon injection followed by FF to control Hg emission from clinical waste incin., ELV = 0.05mgHg/Nm^3		
S1-9	Application of fabric filters or electrostatic precipitators in glass production, ELV = 30mg PM/Nm^3		
S1-10	Reduction of Hg emission in Hg-based process, ELV = 0.5g Hg/tonneCl_2		
S1-11	Control of fugitive emission from coke ovens by capturing and filtering, ELV = 50mg PM/Nm^3		
S1-12	Addition of a fabric filter and evacuation to control fugitive emission from blast furnaces, ELV = 20mg PM/Nm^3		
S1-13	Addition of fabric filters to sinter plant stacks, ELV = 20mg PM/Nm^3		
S1-14	Addition of dry ESP or scrubber to control BOF primary emission, additional control of fugitive emission by fabric filters, ELV = 20mg PM/Nm^3		
S1-15	Addition of fabric filters, scrubbers or ESP to control stack emission from primary Zn smelters, ELV = 5mg PM/Nm^3		
S1-16	Addition of fabric filters to control stack emission from primary Pb smelters, ELV = 5mg PM/Nm^3		

Table Ad.9: Emission in 2020 after full implementation of the HM protocol and emission after a possible revision of the HM Protocol following Package 1+2, associated emission reduction and costs for the EU(25)+.

Sector	Detailed Sub-Sector	Detailed Fuel	Emission 2020 FI existing HM Protocol (tonnes) Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Measure(s)	Costs (M€)
1_PHP	Heat / Power Plants	Brown Coal	1.03	12.83	7.99	7.42	4.62	3.58	6.10		23.11	S2-2	2748
1_PHP	Heat / Power Plants	Hard Coal	1.09	28.66	51.51	16.48	11.15	18.35	23.16	19.35	228.17	S2-2	5136
1_PHP	Heat / Power Plants	Heavy Fuel Oil	2.72	0.86	6.26	3.03	11.56	5.17	118.41	2.84	1.40	S2-1	79
1_PHP	Heat / Power Plants	Peat	0.05	0.68	0.55	0.44	0.38	0.63	0.27		0.87	S2-2	185
1_PHP	Other emission from Heat/Power Plants		1.37	0.32	6.63	0.32	0.59	1.35	3.12	0.07	341.06		
2_RCO	Residential, commercial and other combustion		17.38	5.72	108.77	17.66	30.29	55.11	90.76	2.37	398.27		
3_IND	Cement Production	-	2.38	57.08	27.66	5.87	9.16		15.22	0.59	66.53	S2-3	1652
3_IND	Chlorine Production	-		0.01								S2-4	0
3_IND	Industrial Combustion	Brown Coal	0.01	0.20	0.02	0.07	0.05	0.02	0.05		0.10	S2-2	45
3_IND	Industrial Combustion	Hard Coal	0.13	4.10	5.96	2.45	3.57	1.81	8.23	1.19	20.11	S2-2	554
3_IND	Industrial Combustion	Heavy Fuel Oil	3.37	0.93	6.24	7.18	18.78	4.02	151.68	3.41	2.47	S2-1	71
3_IND	Industrial Combustion	Peat	0.00	0.02	0.00	0.04	0.00	0.00	0.01		0.01	S2-2	9
3_IND	Iron & Steel, Electric Arc Furnace	-	17.84	0.18	99.48	7.46	27.51	33.53	1.96	5.73	1459.63	S1-3	704
3_IND	Iron & Steel, Sinter Production	-	6.68	1.68	359.00	4.58	29.64	42.45	50.31	1.66	83.19	S1-13	350
3_IND	Oil Refineries	Hard Coal	0.00	0.45	0.26	0.33	0.63	0.07	0.66	0.14	1.36	S2-2	101
3_IND	Oil Refineries	Heavy Fuel Oil	2.45	0.59	4.17	6.53	15.99	2.98	110.12	2.40	0.96	S2-1	51
3_IND	Primary Copper Production	-	3.40	0.19	11.83	8.68		70.81			128.07	S1-4	133
3_IND	Primary Lead Production	-	0.77	2.28	145.03	0.88		3.07			21.68	S1-16	43
3_IND	Primary Nickel Production	-					86.16		41.03			S1-5	14
3_IND	Primary Zinc Production	-	3.06	0.55	11.46						373.11	S1-16	59
3_IND	Other emission in Industry		19.31	8.28	838.63	72.79	118.25	180.07	193.85	110.09	3470.31		
4_SPU	Emission from Solvent Use		0.00	0.04	0.02								
5_ROT	Road Transport (Exhaust)	-			844.19							S1-7	
5_ROT	Other Road Transport		7.50	0.07		0.37	23.46	472.61	45.85	3.16	1366.37		
6_NRT	Non-Road Transport		0.21	0.26	6.50	0.68	0.89	179.38	35.71	1.20	12.55		
7_WAS	Incineration	-	0.12	0.20	2.77	0.00	0.05	0.07	0.02	0.00	1.28	S1-8	1
7_WAS	Other emission from Waste Generation and Disposal		4.40	14.99	77.01	1.72	22.57	31.78	7.87	0.62	614.58		
8_AGR	Emission from Agriculture		0.03	0.02	0.07	0.03	0.03	0.07					
Total sectors listed above			95	141	2622	165	415	1107	904	155	8615		11936

Sector	Detailed Sub-Sector	Detailed Fuel	Emission Reduction due to Revision Package 1+2 (tonnes) Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal		10.26							
1_PHP	Heat / Power Plants	Hard Coal		22.92							
1_PHP	Heat / Power Plants	Heavy Fuel Oil	2.72	0.86	6.26	3.03	11.56	5.17	118.41	2.84	1.40
1_PHP	Heat / Power Plants	Peat		0.55							
1_PHP	Other emission from Heat/Power Plants										
2_RCO	Residential, commercial and other combustion										
3_IND	Cement Production	-		11.42							
3_IND	Chlorine Production	-		0.01							
3_IND	Industrial Combustion	Brown Coal		0.16							
3_IND	Industrial Combustion	Hard Coal		3.28							
3_IND	Industrial Combustion	Heavy Fuel Oil	3.37	0.93	6.24	7.18	18.78	4.02	151.68	3.41	2.47
3_IND	Industrial Combustion	Peat		0.01							
3_IND	Iron & Steel, Electric Arc Furnace	-	2.59	0.00	14.45	1.08	11.53	8.06	0.54	0.74	219.11
3_IND	Iron & Steel, Sinter Production	-	2.54	0.06	136.42	1.73	18.08	19.74	24.35	0.55	32.11
3_IND	Oil Refineries	Hard Coal		0.36							
3_IND	Oil Refineries	Heavy Fuel Oil	2.45	0.59	4.17	6.53	15.99	2.98	110.12	2.40	0.96
3_IND	Primary Copper Production	-	1.76	0.01	6.11	4.46		43.74			67.45
3_IND	Primary Lead Production	-	0.38	0.11	72.52	0.44		1.87			11.16
3_IND	Primary Nickel Production	-					74.58		32.44		
3_IND	Primary Zinc Production	-	2.29	0.04	8.60						282.63
3_IND	Other emission in Industry										
4_SPU	Emission from Solvent Use										
5_ROT	Road Transport (Exhaust)	-			827.11						
5_ROT	Other Road Transport										
6_NRT	Non-Road Transport										
7_WAS	Incineration	-		0.08							
7_WAS	Other emission from Waste Generation and Disposal										
8_AGR	Emission from Agriculture										
Total sectors listed above			18	52	1082	24	151	86	438	10	617

Sector	Detailed Sub-Sector	Detailed Fuel	Emission after Protocol Revision Package 1+2 (tonnes) Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	1.03	2.57	7.99	7.42	4.62	3.58	6.10		23.11
1_PHP	Heat / Power Plants	Hard Coal	1.09	5.73	51.51	16.48	11.15	18.35	23.16	19.35	228.17
1_PHP	Heat / Power Plants	Heavy Fuel Oil									
1_PHP	Heat / Power Plants	Peat	0.05	0.14	0.55	0.44	0.38	0.63	0.27		0.87
1_PHP	Other emission from Heat/Power Plants		1.37	0.32	6.63	0.32	0.59	1.35	3.12	0.07	341.06
2_RCO	Residential, commercial and other combustion		17.38	5.72	108.77	17.66	30.29	55.11	90.76	2.37	398.27
3_IND	Cement Production	-	2.38	45.66	27.66	5.87	9.16		15.22	0.59	66.53
3_IND	Chlorine Production	-									
3_IND	Industrial Combustion	Brown Coal	0.01	0.04	0.02	0.07	0.05	0.02	0.05		0.10
3_IND	Industrial Combustion	Hard Coal	0.13	0.82	5.96	2.45	3.57	1.81	8.23	1.19	20.11
3_IND	Industrial Combustion	Heavy Fuel Oil									
3_IND	Industrial Combustion	Peat	0.00	0.00	0.00	0.04	0.00	0.00	0.01		0.01
3_IND	Iron & Steel, Electric Arc Furnace	-	15.24	0.18	85.02	6.38	15.99	25.47	1.42	4.99	1240.52
3_IND	Iron & Steel, Sinter Production	-	4.14	1.62	222.58	2.85	11.56	22.71	25.96	1.11	51.08
3_IND	Oil Refineries	Hard Coal	0.00	0.09	0.26	0.33	0.63	0.07	0.66	0.14	1.36
3_IND	Oil Refineries	Heavy Fuel Oil									
3_IND	Primary Copper Production	-	1.64	0.18	5.72	4.22		27.07			60.62
3_IND	Primary Lead Production	-	0.38	2.17	72.52	0.44		1.20			10.51
3_IND	Primary Nickel Production	-					11.58		8.59		
3_IND	Primary Zinc Production	-	0.76	0.51	2.87						90.48
3_IND	Other emission in Industry		19.31	8.28	838.63	72.79	118.25	180.07	193.85	110.09	3470.31
4_SPU	Emission from Solvent Use		0.00	0.04	0.02						
5_ROT	Road Transport (Exhaust)	-			17.07						
5_ROT	Other Road Transport		7.50	0.07		0.37	23.46	472.61	45.85	3.16	1366.37
6_NRT	Non-Road Transport		0.21	0.26	6.50	0.68	0.89	179.38	35.71	1.20	12.55
7_WAS	Incineration	-	0.12	0.12	2.77	0.00	0.05	0.07	0.02	0.00	1.28
7_WAS	Other emission from Waste Generation and Disposal		4.40	14.99	77.01	1.72	22.57	31.78	7.87	0.62	614.58
8_AGR	Emission from Agriculture		0.03	0.02	0.07	0.03	0.03	0.07			
Total sectors listed above			77	90	1540	141	265	1021	467	145	7998

See Table Ad. 8 for legend to abbreviation of measures

Table Ad. 10: Emission in 2020 after full implementation of the HM protocol and emission after a possible revision of the HM Protocol following Package 1+2, associated emission reduction and costs for the non-EU(25)+.

Sector	Detailed Sub-Sector	Detailed Fuel	Emission 2020 FI existing HM Protocol (tonnes)									Measure(s)	Costs (M€)	Emission Reduction due to Revision Package 1+2 (tonnes)									Emission after Protocol Revision Package 1+2 (tonnes)								
			Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn			Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
1_PHP	Heat / Power Plants	Brown Coal	9.61	24.30	19.17	4.11	1.24	16.52	2.83		100.89	S1-2 + S2-2	5317	5.55	19.44	11.07	2.36	0.89	10.57	1.78		59.07	4.06	4.86	8.10	1.75	0.35	5.95	1.05		41.83
1_PHP	Heat / Power Plants	Hard Coal	6.07	53.97	302.97	18.73	2.52	50.09	9.88	13.69	612.13	S1-2 + S2-2	5796	3.51	43.18	174.95	10.76	1.80	32.06	6.20	6.82	358.37	2.57	10.79	128.03	7.97	0.72	18.03	3.67	6.87	253.77
1_PHP	Heat / Power Plants	Heavy Fuel Oil	17.13	5.45	30.07	18.21	43.50	16.78	890.84	16.48	3.48	S2-1	342	17.13	5.45	30.07	18.21	43.50	16.78	890.84	16.48	3.48									
1_PHP	Heat / Power Plants	Peat	0.05	0.12	0.10	0.02	0.01	0.08	0.01		0.02	S1-2 + S2-2	42	0.03	0.10	0.06	0.01	0.00	0.05	0.01		0.01	0.02	0.02	0.04	0.01	0.00	0.03	0.01		0.01
1_PHP	*Other emission from Heat/Power Plants*		*0.22*	*0.07*	*1.21*	*0.26*	*0.36*	*0.75*	*1.95*	*0.06*	*54.43*												*0.22*	*0.07*	*1.21*	*0.26*	*0.36*	*0.75*	*1.95*	*0.06*	*54.43*
2_RCO	*Residential, commercial and other combustion*		*16.17*	*19.64*	*143.47*	*16.61*	*59.88*	*130.39*	*161.19*	*7.59*	*609.84*												*16.17*	*19.64*	*143.47*	*16.61*	*59.88*	*130.39*	*161.19*	*7.59*	*609.84*
3_IND	Cement Production	-	0.42	33.93	4.31	0.39	1.15		3.27	0.10	7.46	S1-6 + S2-3	1120	0.12	6.79	1.24	0.11	0.52		1.20	0.03	2.17	0.30	27.15	3.07	0.28	0.63		2.07	0.08	5.29
3_IND	Chlorine Production	-		2.62								S2-4	29		2.62																
3_IND	Coke Ovens	-	10.81	6.25	46.62	4.15	35.26	18.67	13.48		45.63	S1-11	1241	2.58	0.15	11.11	0.98	17.63	6.74	4.47		11.63	8.23	6.10	35.51	3.16	17.63	11.93	9.01		34.00
3_IND	Glass Production	-	1.32	0.22	82.23	0.53	11.01	2.85	8.72	81.87	53.60	S1-9	9	0.92	0.02	57.56	0.37	8.74	2.07	6.53	49.41	37.52	0.40	0.20	24.67	0.16	2.27	0.77	2.19	32.46	16.08
3_IND	Industrial Combustion	Brown Coal	0.01	0.06	0.01	0.00	0.00	0.01	0.00		0.06	S1-2 + S2-2	11	0.00	0.05	0.01	0.00	0.00	0.01	0.00		0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00		0.02
3_IND	Industrial Combustion	Hard Coal	0.05	1.02	1.93	0.11	0.18	0.29	0.42	0.14	3.35	S1-2 + S2-2	116	0.03	0.82	1.12	0.06	0.13	0.19	0.26	0.07	1.96	0.02	0.20	0.82	0.05	0.05	0.10	0.16	0.07	1.39
3_IND	Industrial Combustion	Heavy Fuel Oil	4.23	1.09	7.66	3.93	8.58	3.77	163.10	3.08	0.76	S2-1	65	4.23	1.09	7.66	3.93	8.58	3.77	163.10	3.08	0.76									
3_IND	Industrial Combustion	Peat	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	S1-2 + S2-2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
3_IND	Iron & Steel, Blast	-	1.72	1.97	421.93	12.43	7.78	68.84	18.23	3.38	1237.62	S1-12	84	0.87	0.10	213.22	6.25	5.28	38.73	10.76	1.48	627.89	0.85	1.87	208.72	6.18	2.50	30.11	7.47	1.90	609.74
3_IND	Iron & Steel, Electric Arc Furnace	-	2.63	0.13	14.96	0.61	6.61	5.90	0.75	0.65	141.94	S1-3	242	0.38	0.00	2.17	0.09	2.77	1.42	0.21	0.08	21.31	2.24	0.13	12.79	0.52	3.84	4.48	0.54	0.56	120.63
3_IND	Iron & Steel, Oxygen Furnace	-	2.02	0.23	117.87	1.15	7.64	7.64	3.82	0.23	305.47	S1-14	527	1.62	0.02	94.43	0.91	6.82	6.45	3.18	0.16	246.56	0.40	0.21	23.43	0.23	0.82	1.19	0.64	0.07	58.90
3_IND	Iron & Steel, Sinter Production	-	3.12	1.92	184.05	1.22	5.87	15.02	18.52	0.80	29.36	S1-13	321	1.51	0.09	89.01	0.59	4.03	8.45	10.57	0.34	14.40	1.61	1.82	95.04	0.63	1.85	6.57	7.95	0.47	14.96
3_IND	Oil Refineries	Hard Coal	0.00	0.06	0.03	0.00	0.01	0.01	0.02	0.00	0.17	S1-2 + S2-2	15	0.00	0.05	0.02	0.00	0.00	0.01	0.01		0.10	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.07
3_IND	Oil Refineries	Heavy Fuel Oil	0.97	0.23	1.47	0.78	1.85	0.73	35.25	0.64	0.15	S2-1	14	0.97	0.23	1.47	0.78	1.85	0.73	35.25	0.64	0.15									
3_IND	Primary Copper	-	19.69	0.16	98.47	49.39		240.40			490.89	S1-4	101	14.64	0.01	73.20	36.53		191.52			367.35	5.05	0.14	25.27	12.86		48.88			123.54
3_IND	Primary Lead Production	-	2.16	1.27	179.92	1.08		2.89			28.40	S1-16	17	1.08	0.06	89.96	0.54		1.76			14.62	1.08	1.21	89.96	0.54		1.13			13.77
3_IND	Primary Nickel Production	-					236.74		92.33			S1-5	22					226.67		85.50							10.08		6.84		
3_IND	Primary Zinc Production	-	8.57	4.37	21.28						426.42	S1-15	22	6.43	0.33	15.96						323.02	2.14	4.04	5.32						103.41
3_IND	*Other emission in Industry*		*12.30*	*14.27*	*250.34*	*18.51*	*46.64*	*64.79*	*253.18*	*9.19*	*592.93*												*12.30*	*14.27*	*250.34*	*18.51*	*46.64*	*64.79*	*253.18*	*9.19*	*592.93*
4_SPU	*Emission from Solvent Use*																														
5_ROT	Road Transport (Exhaust)	-			1102.00							S1-7				1014.36									87.64						
5_ROT	*Other Road Transport*		*1.63*				*7.40*	*188.13*	*11.12*	*1.01*	*390.17*												*1.63*				*7.40*	*188.13*	*11.12*	*1.01*	*390.17*
6_NRT	*Non-Road Transport*		*0.41*	*0.08*	*105.23*	*0.82*	*0.60*	*184.05*	*28.14*	*0.65*	*8.19*												*0.41*	*0.08*	*105.23*	*0.82*	*0.60*	*184.05*	*28.14*	*0.65*	*8.19*
7_WAS	Clinical Waste	-	0.03	0.26	0.96	0.00	0.00	0.01	0.00	0.00	0.16	S1-8	0.4		0.10								0.03	0.16	0.96	0.00	0.00	0.01	0.00	0.00	0.16
7_WAS	*Other emission from Waste Generation and Disposal*		*0.09*	*0.98*	*0.67*	*0.02*	*0.14*	*0.32*	*0.06*	*0.01*	*6.44*												*0.09*	*0.98*	*0.67*	*0.02*	*0.14*	*0.32*	*0.06*	*0.01*	*6.44*
8_AGR	*Emission from Agriculture*		*0.01*	*0.01*	*0.01*	*0.00*	*0.01*	*0.01*	*0.18*														*0.01*	*0.01*	*0.01*	*0.00*	*0.01*	*0.01*	*0.18*		
Total sectors listed above			121	175	3139	153	485	1019	1717	140	5150		15454	62	81	1889	82	329	321	1220	79	2090	60	94	1250	71	156	698	497	61	3060

See Table Ad. 8 for legend to abbreviation of measures