Revision of the Heavy Metal Protocol: calculation of emissions, costs, depositions and exceedances of some scenarios.

(TNO, MSC-E and CCE)

Extended summary

1. Introduction

Long-range transport of air pollution is an important factor affecting ecosystems and the human population. The United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) is aimed at reducing and preventing air pollution. The Convention has produced a number of legally binding protocols covering specific categories of air pollutants. The Protocol on Heavy Metals (HM) was signed in 1998 and came into force in 2003. The objective of the HM Protocol is to introduce measures for the reduction of cadmium (Cd), lead (Pb) and mercury (Hg) emissions into the atmosphere, with a view to preventing adverse effects on human health and the environment. It describes the measures and the best available techniques for controlling emissions, and indicates programs, strategies and policies for achieving the heavy metals limit values specified in the protocol.
Currently the process for the revision of the Heavy Metal Protocol is underway. A draft text for the revised protocol and it's annexes has been submitted by Switzerland (ECE/EB.AIR/WG.5/2010/6). This draft has partly been prepared based on the results of the work of the Task Force on Heavy Metals.

2. The research project

To support the negotiations on the proposed amendments on the Heavy Metal Protocol a research project has been commissioned by the Netherlands producing four scenario's for which emissions, costs of emission reductions, depositions and exceedances of critical loads have been calculated. The four scenario's for cadmium, lead and mercury are:

1. 2010 current legislation and current ratification of the HM Protocol (CLE)
2. 2020 full ratification of the HM Protocol (FIHM)
3. 2020 full ratification of the amended HM Protocol Option 1 for dust plus Hg measures (Option 1)
4. 2020 full ratification of the amended HM Protocol Option 2 for dust plus Hg measures (Option 2)

The "options" under scenario 3 and 4 refer to the specific emissions limit values (ELV's) for particulate matter (PM) that are proposed in the draft revised protocol. Option 1 is the most ambitious, while Option 2 is somewhat less stringent. The study covers all countries taking part in the LRTAP Convention which belong to the European domain.

The research project is a cooperative effort of several research institutions. First, TNO, Netherlands Organisation for Applied Scientific Research, made a projection of the emissions and emission reductions under the four scenario's. TNO also estimated the additional costs of the measures involved. Then, these emission data were used by the Meteorological Synthesizing Centre-East (MSC East) for calculating depositions of the various scenarios. Finally, these depositions were used by the Coordination Centre for Effects (CCE) of the Netherlands Environmental Assessment Agency (PBL) to determine to what extent critical loads for ecosystems and human health would be exceeded.

3. Emissions

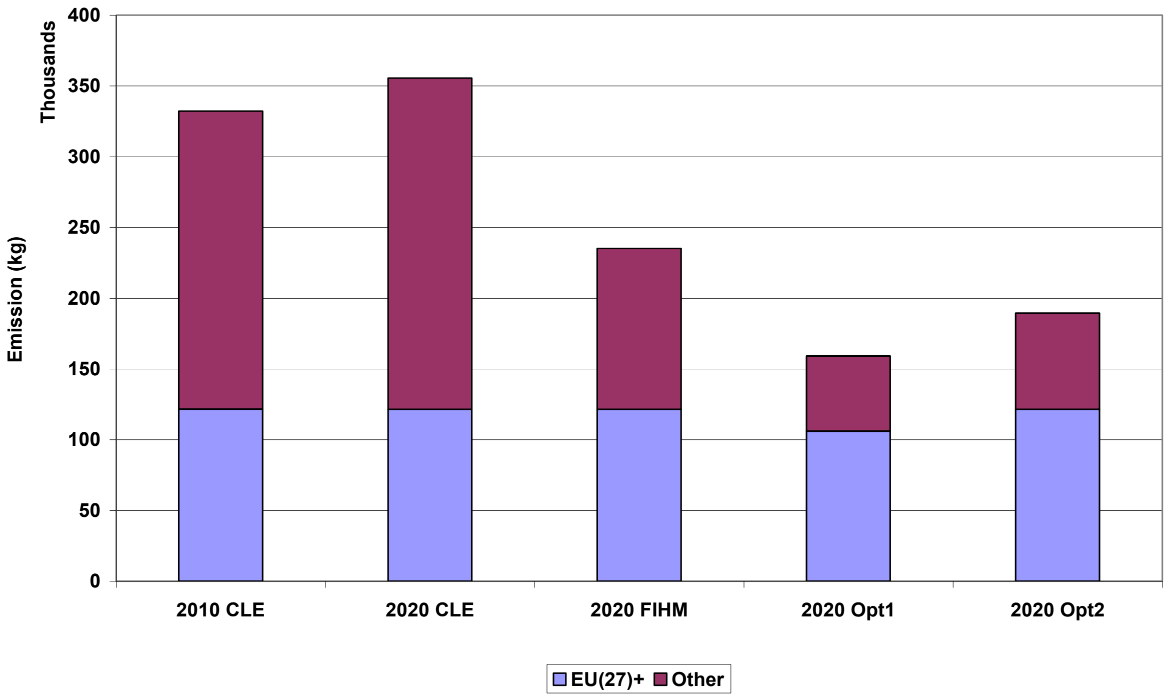
To assess the impact of a possible revision of the HM Protocol, 2010 was chosen as the base year for the emission data. Since no reported data for 2010 are available yet, a baseline emission data set was compiled from a combination of projected emission data from a similar TNO study in 2005 and the most recent officially reported country emission data (2007). In case no officially reported data were available, the TNO projected emissions were used. When both officially reported data and TNO projections were available these datasets were compared. If the two estimates were within a factor two from each, the reported emission was used. If the two estimates differed more than a factor two then the estimate was chosen which is closest tot the independent ESPREME heavy metal inventory which started in 2004. In the case of Germany the TNO emission estimate for 2010 was adjusted because of a high discrepancy with the officially reported data.

Based on the emission data set compiled for 2010 as described above, projections were made for the emissions of cadmium, mercury and lead under the different scenarios.

Cadmium

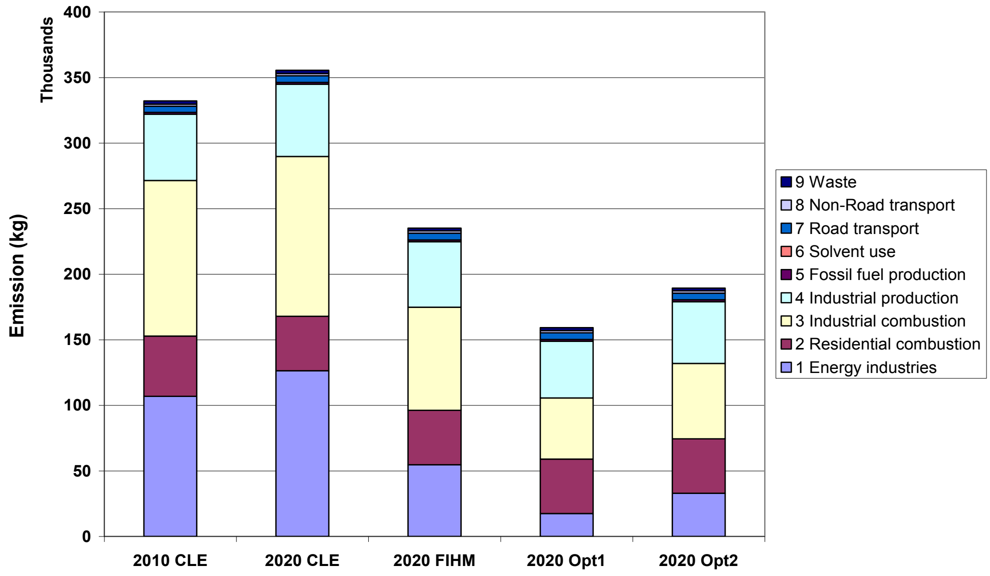
Under current legislation the emission of Cd will grow slightly with 7% to 356 tonnes per year in 2020 (figure 1). Full implementation of the HM protocol reduces the total emission with 120 tonnes per year due to measures in the non-EU27 countries that not ratified the HM protocol as of 2009. The Option 1 scenario is more stringent than Option 2; compared to the FIHM scenario emissions are reduced by 76 and 46 tonnes/yr, respectively.

Figure 1: Cadmium emission in UNECE Europe following different scenarios. (EU 27+ stands for the 27 EU member states plus Norway and Switzerland).



Under the current legislation, cadmium emissions are dominated by the energy production sector and industrial combustion (figure 2). These sectors are addressed in the FIHM scenario and even more so in the Option 1 and Option 2 scenarios. The result is that eventually the Cd emissions from the sectors Energy industries, Residential combustion, Industrial combustion and Industrial production may be of the same order of magnitude. The absolute ranking of the source sector importance varies depending on the selected scenario with Option 1 resulting in lowest emissions and effectively addressing the energy industries sector

Figure 2: Cadmium emissions in UNECE Europe by source sector following different scenarios.



Mercury

Under current legislation the emission of Hg will grow with 15% to 292 tonnes per year in 2020 (figure 3). Full implementation of the HM protocol reduces the total emission with only 12 tonnes per year.

For mercury there is little difference between the Option 1 scenario and Option 2 scenario as these scenarios assume implementation of the same Hg measures; compared to the FIHM scenario emissions are reduced by 67 and 61 tonnes/yr, respectively. The small additional reduction under the Option 1 scenario was caused by the dust control measures in the energy transformation sector (power plants).

Under the current legislation, mercury emissions are dominated by the energy production sector and industrial combustion (figure 4). This remains the case following the FIHM scenario. Under the Option 1 and Option 2 scenarios only the Hg emission from industrial combustion will be abated. The result was that the Hg emissions are dominated by the Energy production sector (~ 60%) and industrial combustion (~23%).

Figure 3: Mercury emission in UNECE Europe following different scenarios. (EU 27+ stands for the 27 EU member states plus Norway and Switzerland).

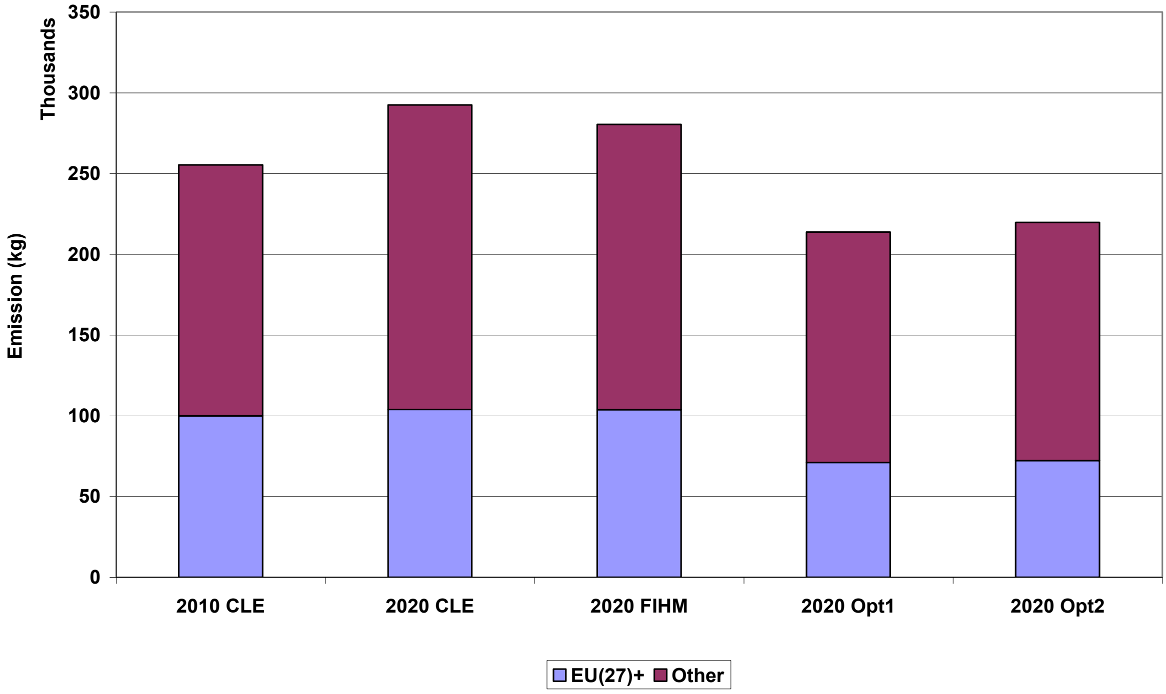
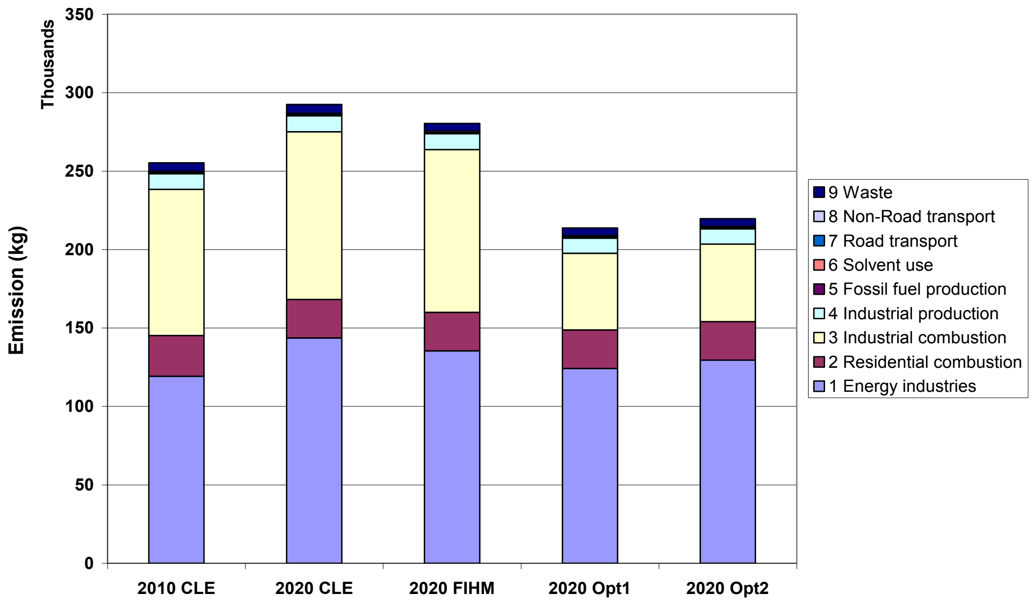


Figure 4: Mercury emissions in UNECE Europe by source sector following different scenarios.



Lead

Under current legislation the emission of Pb will grow slightly with 5% to 6230 tonnes per year in 2020 (figure 5). Full implementation of the HM protocol reduces the total emission with 2253 tonnes per year due to measures in the non-EU27 countries that not ratified the HM protocol as of 2009. The Option 1 scenario is more stringent than Option 2; compared to the FIHM scenario emissions are reduced by 1598 and 866 tonnes/yr, respectively. Under the current legislation, lead emissions are dominated by the energy production sector, industrial combustion and industrial production (figure 6). These sectors are addressed in the FIHM scenario and even more so in the Option 1 and Option 2 scenarios. The result is that eventually the lead emissions from the energy industries (power plants) are significantly reduced and the lead emission is dominated by industry sectors (combustion and production).

Figure 5: Lead emissions in UNECE Europe following different scenarios. (EU 27+ stands for the 27 EU member states plus Norway and Switzerland).

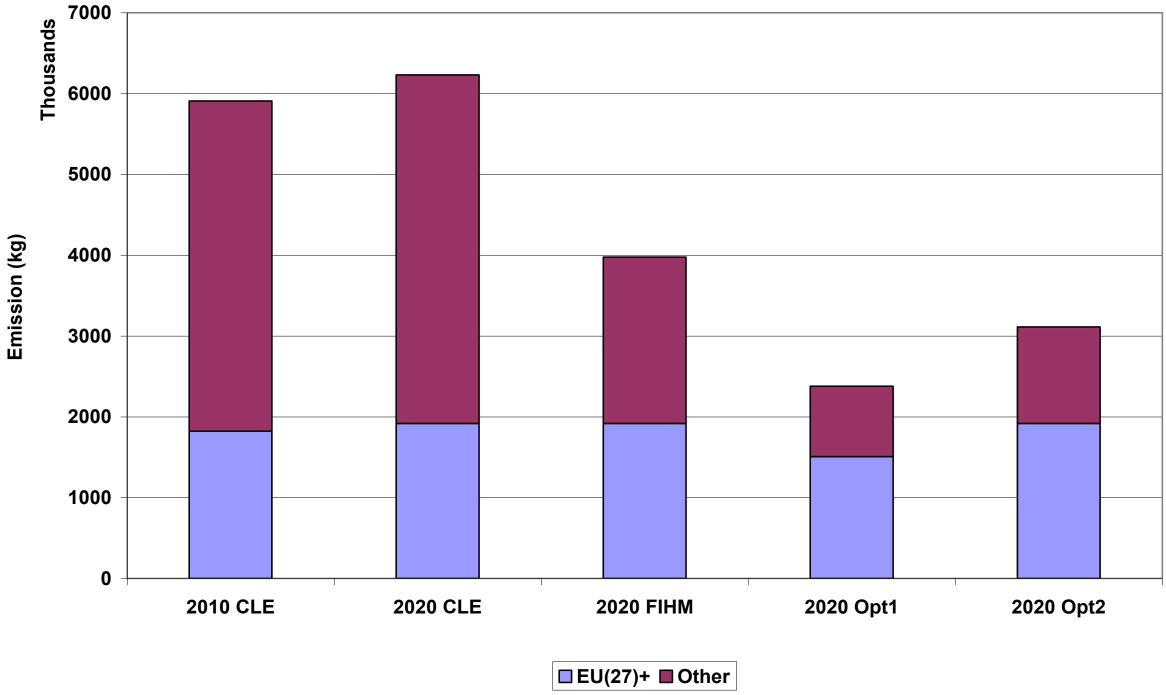
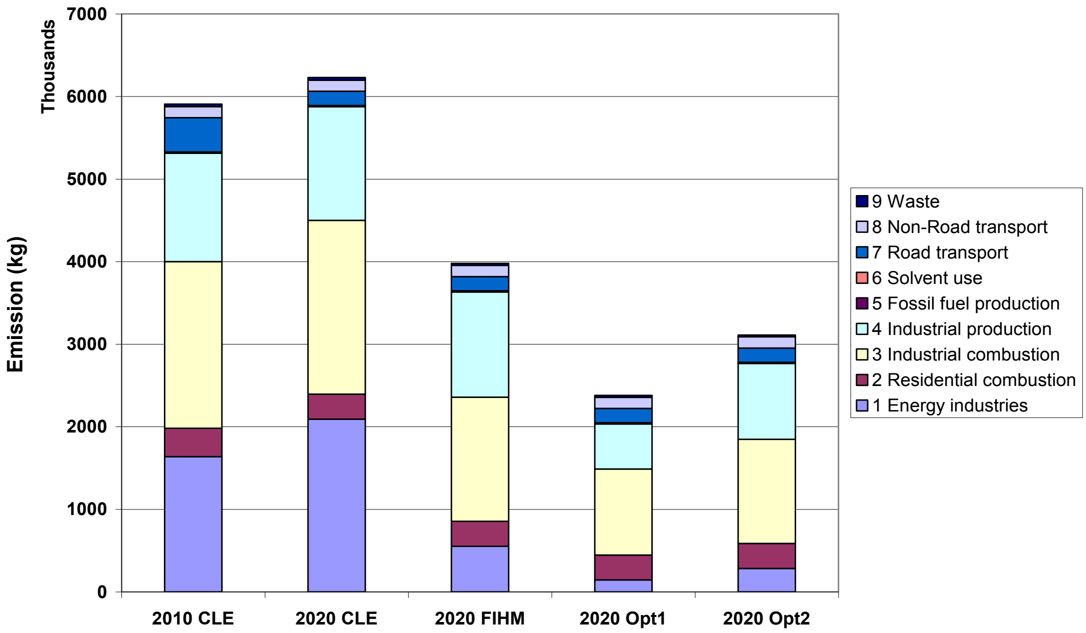


Figure 6: Lead emissions in UNECE Europe by source sector following different scenarios.

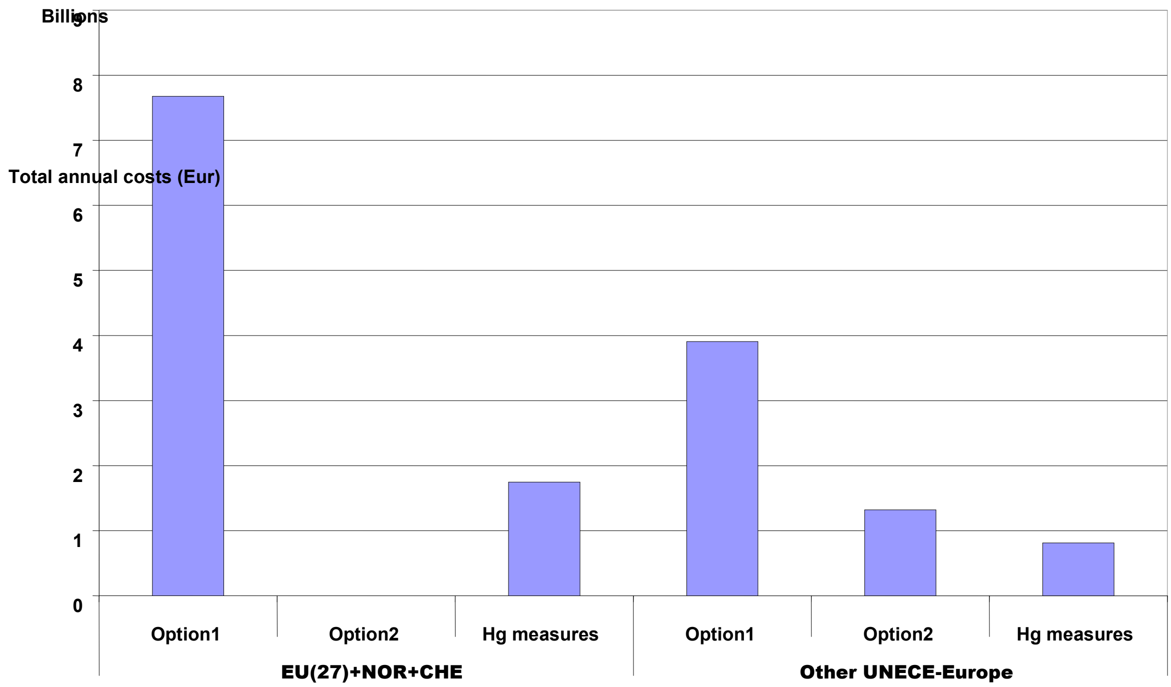


4. Costs of emission reduction

Starting point for the estimation of the effects and costs of amending the current HM Protocol according to Option 1 and Option 2 is the projected HM emission in 2020 (2020 FIHM) after full implementation of the current Protocol (also for countries that have not ratified) plus all agreed and planned emission reduction measures under current legislation (e.g. IPCC Directive and other UNECE Protocol for countries that have ratified them). Then, specific measures and control technologies that result in achieving the specific ELV's were identified for each individual sector to estimate the costs of implementation of Option 1 and Option 2.

The results show that the revision of the HM protocol following Option 2 is less ambitious than Option1 and as a consequence less expensive. Total estimated costs for implementation of Option 2 in UNECE Europe are € 1.3 billion. These costs will have to be met by the Non-EU(27)+NOR+CHE countries (Other UNECE-Europe; figure 7). This is somewhat misleading because the costs will also be made by EU(27)+ countries, but as a consequence of the IPPC and other EU directives and not due to a revision of the HM protocol. Hence it is considered current legislation and by definition no "additional" costs are to be made by the EU(27)+ to meet Option 2.
Option 1 is more ambitious and substantially more expensive. Total costs in UNECE-Europe are estimated at € 11.6 billion. The majority of these costs (66%) will have to be met by the EU(27)+ countries (Figure 7). Clearly the more stringent Option ELVs are not covered by current legislation and therefore, cause additional costs for all countries in UNECE Europe. Total costs for implementing the additional Hg measures was estimated at € 2.6 billion; again about 2/3 of these costs are located in the EU27+ countries and about 1/3 in other UNECE-Europe (figure 7).

Figure 7: Estimated annual costs upon revision of the HM Protocol following Option 1, Option 2 and additional Hg measures for the EU(27)+Norway+Switzerland and for other UNECE-Europe countries



Split by source-sector it is evident that the Option 1 costs are dominated by the coal-fired power plants and the additional Hg measures are dominated by cement production. The costs for Option 2 have a more diverse origin. The major costs are expected to be made in the iron

and steel industry, other sectors with substantial costs for Option 2 are the non-ferrous industry and coal-fired power plants
It is remarkable that the additional Hg measures, which yield only limited emission reductions, only bring about substantial costs in the cement production industry despite the fact that it is not the largest source of Hg in UNECE Europe. The key here is that coal-fired power plants on average meet the proposed ELV of the additional Hg measure but due to the large flow rates of flue gasses, they still emit substantial Hg.

The cost estimations presented here provide only an indication of the costs of different measures, since there is a considerable uncertainty, especially when distinguishing at the individual sector level between the two revision packages. Moreover, for several sectors the same measures to achieve both options may well be the same. Therefore, on the basis of the present study it is not feasible to differentiate in cost-effectiveness between Options 1 and 2.

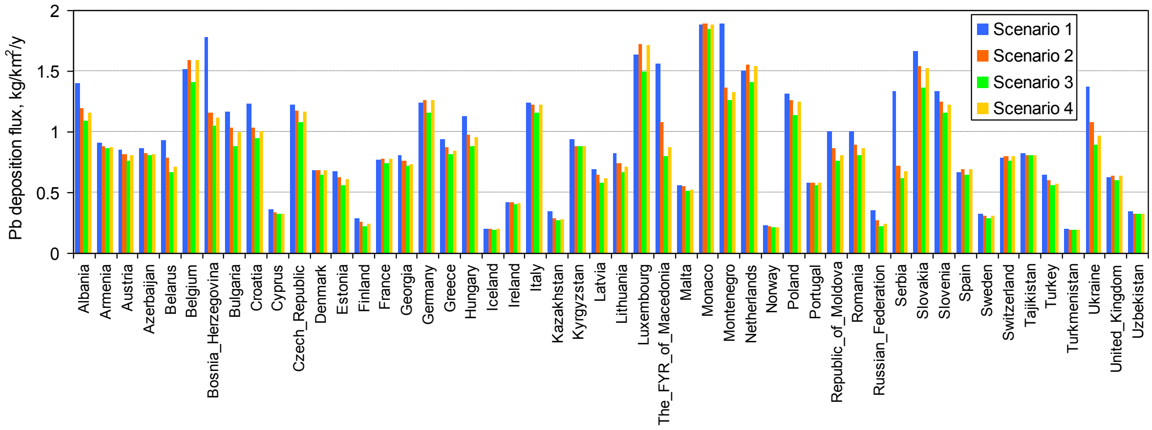
5. Depositions

The four emission datasets prepared by TNO were used by MSC-E to calculate the hemispheric transport and deposition of Cadmium, Mercury and Lead. For this purpose the EMEP heavy metal model MSCE-HM was used. Since deposition also depends on emissions outside the European domain of LRTAP convention, additional emission data were prepared by MSC-E on the Central Asian region, the eastern part of Russia, northern Africa and other remaining parts of Asia.

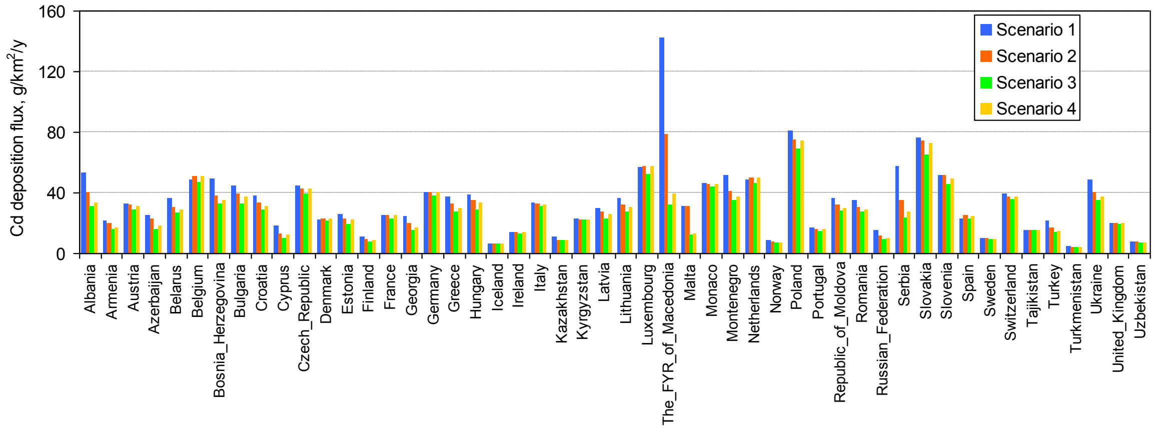
Comparison of country-averaged deposition simulated on the base of different emission scenarios demonstrated that the most significant changes in heavy metal pollution levels are projected for countries located in the south-eastern and the eastern parts of Europe (figure 8). In countries of the central, western and the northern parts of Europe the differences in deposition are relatively small. The reason for this is connected with the scenarios of the emission changes used in this study. Most of countries in the central, western and the northern parts of Europe have already ratified the Protocol on Heavy Metals, and their emissions have already declined following the requirements of the Protocol. Therefore, according to the considered scenarios the long-term changes of the emissions in these countries are relatively low. Hence, changes of deposition in these countries are expected to be insignificant. A number of countries of south-eastern and eastern Europe (e.g., Bosnia and Herzegovina, Montenegro, Kazakhstan, Russia, Ukraine, etc.) have not yet joined the Protocol. Since TNO emission scenarios for 2020 assume full implementation of the Protocol in all EMEP countries, significant changes in emissions, and consequently, in calculated pollution levels of heavy metals are expected.

Spatial distributions of deposition calculated on the base of various emission scenarios look quite similar in countries where differences in total emissions are relatively small, and vice versa. Figure 9 exemplifies maps of lead, cadmium and mercury deposition based on two scenario's, 2010 current legislation and 2020 Option 1). The most distinguished changes in deposition are seen in the central part of Russia, the eastern part of Ukraine, in the south-eastern part of Europe (e.g., Romania, Bulgaria, Serbia, Croatia). In the western, central and northern parts of Europe the changes in deposition fields are minor.

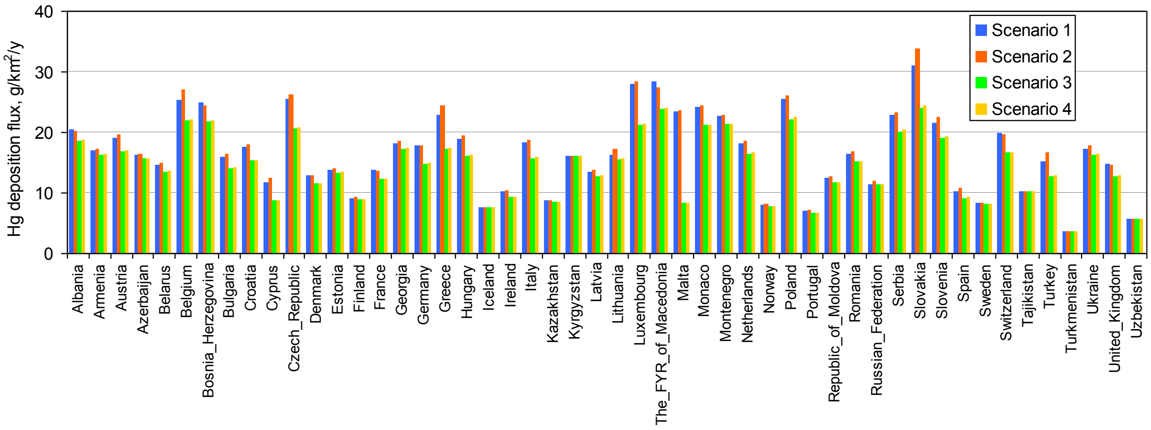
Figure 8: Country-averaged deposition fluxes of lead (a), cadmium (b) and mercury (c) to countries of Europe and Central Asia calculated on the base of different TNO emission scenarios.



a

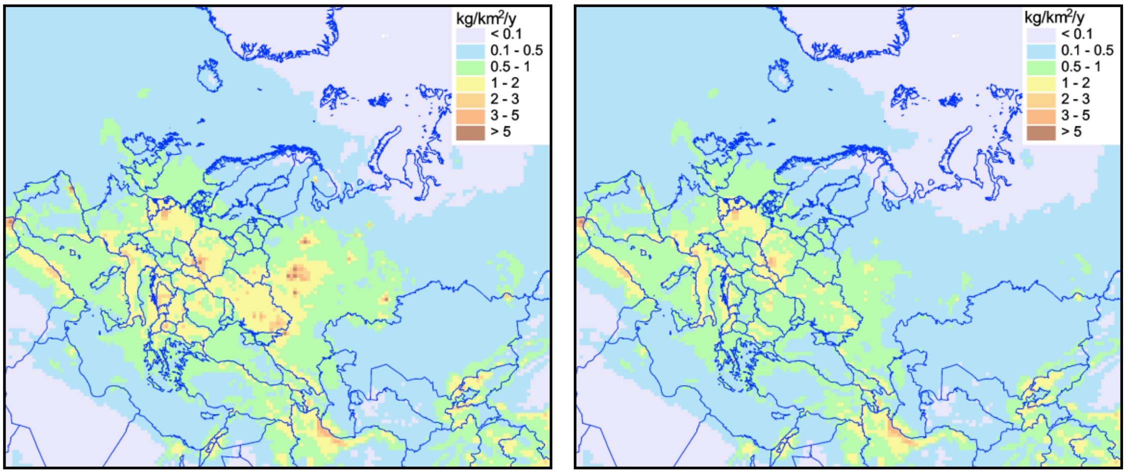


b

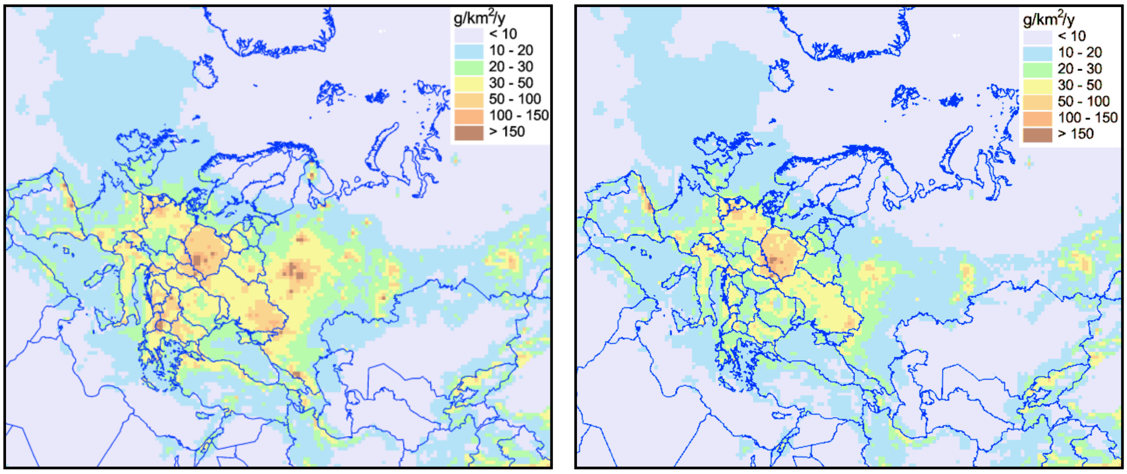


c

Figure 9: Spatial distributions of total deposition of lead (a), cadmium (b) and mercury (c) based on emission 2010 CLE (left) and 2020 Option 1 (right).



a



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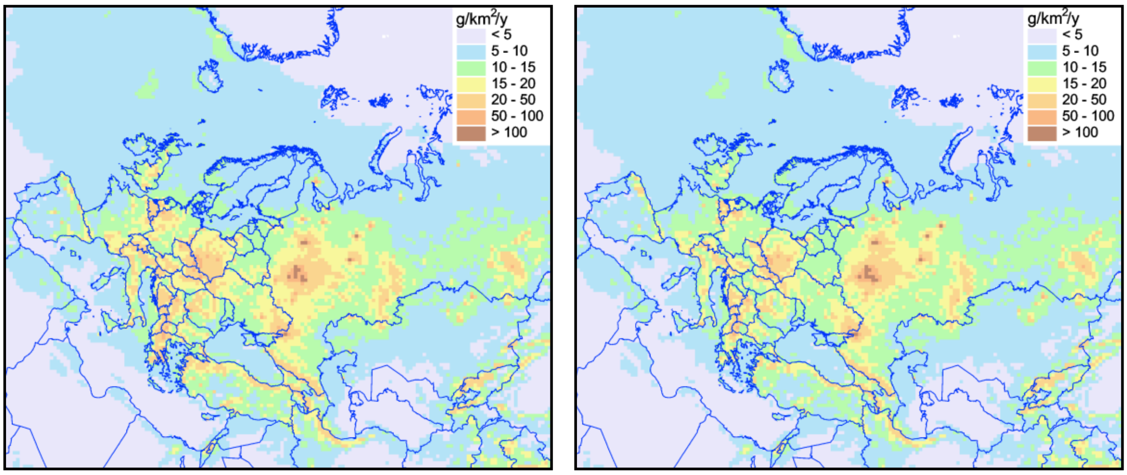


c

6. Critical loads and exceedances

A critical load has been defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge. Exceedance of the critical loads for heavy metals can have several types of effects:

1= human health effect (drinking water) via terrestrial ecosystem;
2= human health effect (food quality) via terrestrial ecosystems;
3= Eco-toxicological effect on terrestrial ecosystems;
4= Eco-toxicological effect on aquatic ecosystems;
5= human health effect (food quality) via aquatic ecosystems.

Effects 1 to 4 are based on critical concentrations of the metal in the soil solution. Using a mass balance for the root layer, this concentration is related to the deposition. Fertilisation of agricultural areas also causes cadmium and lead to enter soil systems, but this is not taken into account in this assessment. For each ecosystem the minimum of the critical loads for all effects is taken. Effect 5 is directly related to the concentration in rainwater.

CCE compiled a set of critical loads for human health effects, eco-toxicological effects and for the critical concentration of mercury in rainwater. These critical loads are based on the country response on the 2005 call for data regarding critical loads for heavy metals initiated by the WGE, complemented by the CCE background database for countries that did not submit any data.

Using the deposition data provided by MSC-E the exceeded area of ecosystems and the Accumulated Average Exceedance (AAE) were calculated. An AAE is the ecosystem area-weighted sum of individual exceedances of all ecosystems in a grid cell.

The results show that the share of exceeded area of ecosystems in the European countries for Cd are all below 1 %, with the exception of Bulgaria, which has lower critical loads than countries in that region. For Pb the area and size of the exceedances are much higher, only few countries are not exceeded. Hg has the largest exceedances, more that half of the countries have over 90% of their ecosystem area exceeded. Also for effect 5 (Hg), for which three countries have submitted critical loads, the exceedance of the critical concentration is widespread. The reductions in exceedances in this case are minimal for Option 1 and 2 that also include specific Hg measures.

The exceedances were also calculated for each EMEP grid. Maps of the Average Accumulated Exceedance (AAE) of Cd, Pb and Hg for current legislation (CLE) in 2010 and for the scenarios with full implementation and the addition Options 1 and 2 (in 2020) are shown in figures 10, 11 and 12. The exceedances of Pb and Hg are widespread over Europe, for Cd exceedance exists in few grids, mostly in Russia. Exceedances are reduced by the measures but remain present in the vast majority of the grids exceeded at present.

Figure 10: Exceedance (AAE) of critical loads for Cd for three scenarios, with the present (CLE 2010) as a reference. The left column shows the exceedance for health effects (1 and 2), the middle for eco-toxicological effect (3 and 4), the rightmost column for all effects combined.

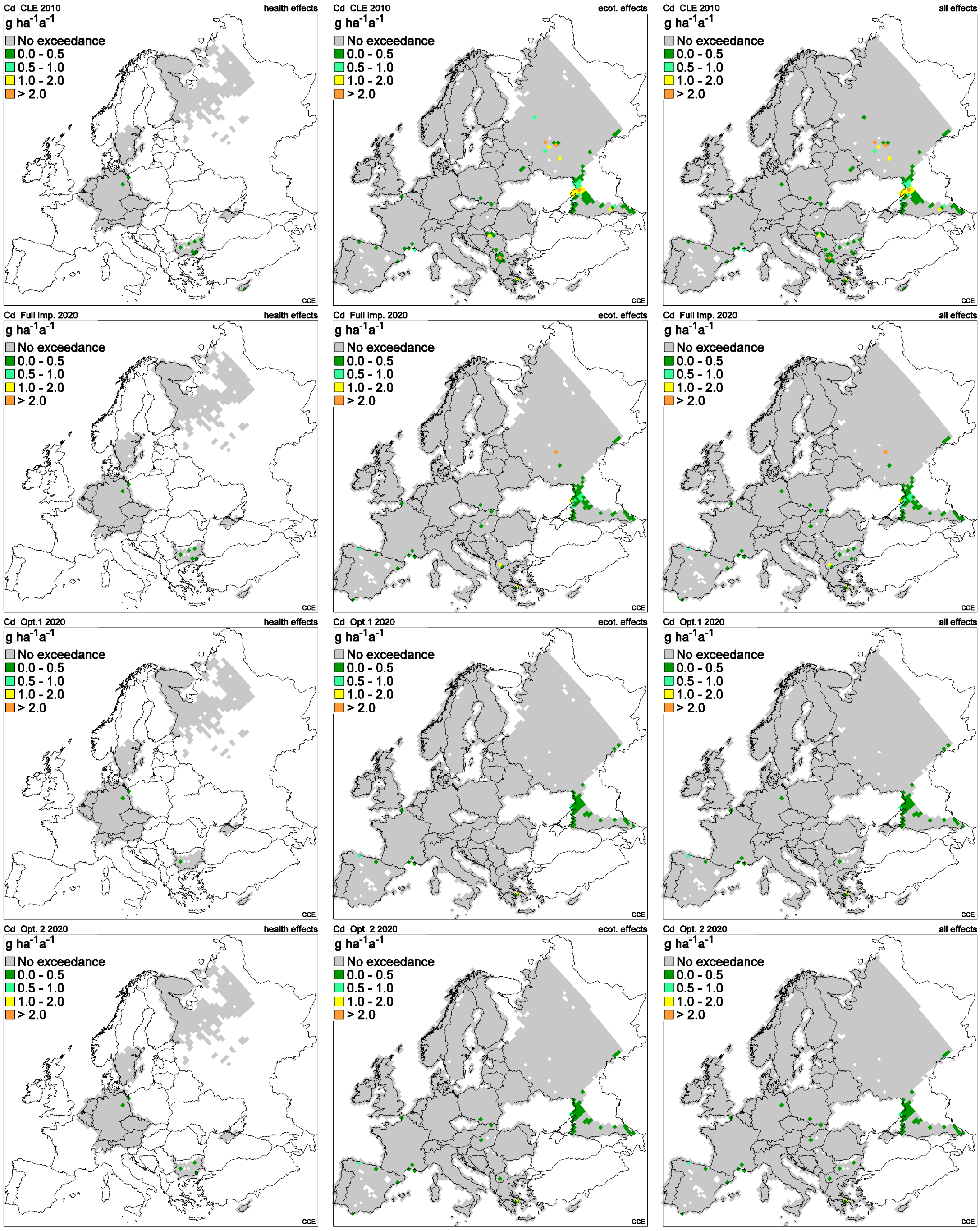


Figure 11: Exceedance (AAE) of critical loads for Pb for three scenarios, with the present (CLE 2010) as a reference. The left column shows the exceedance for health effects (1 and 2), the middle for eco-toxicological effect (3 and 4), the rightmost column for all effects combined.

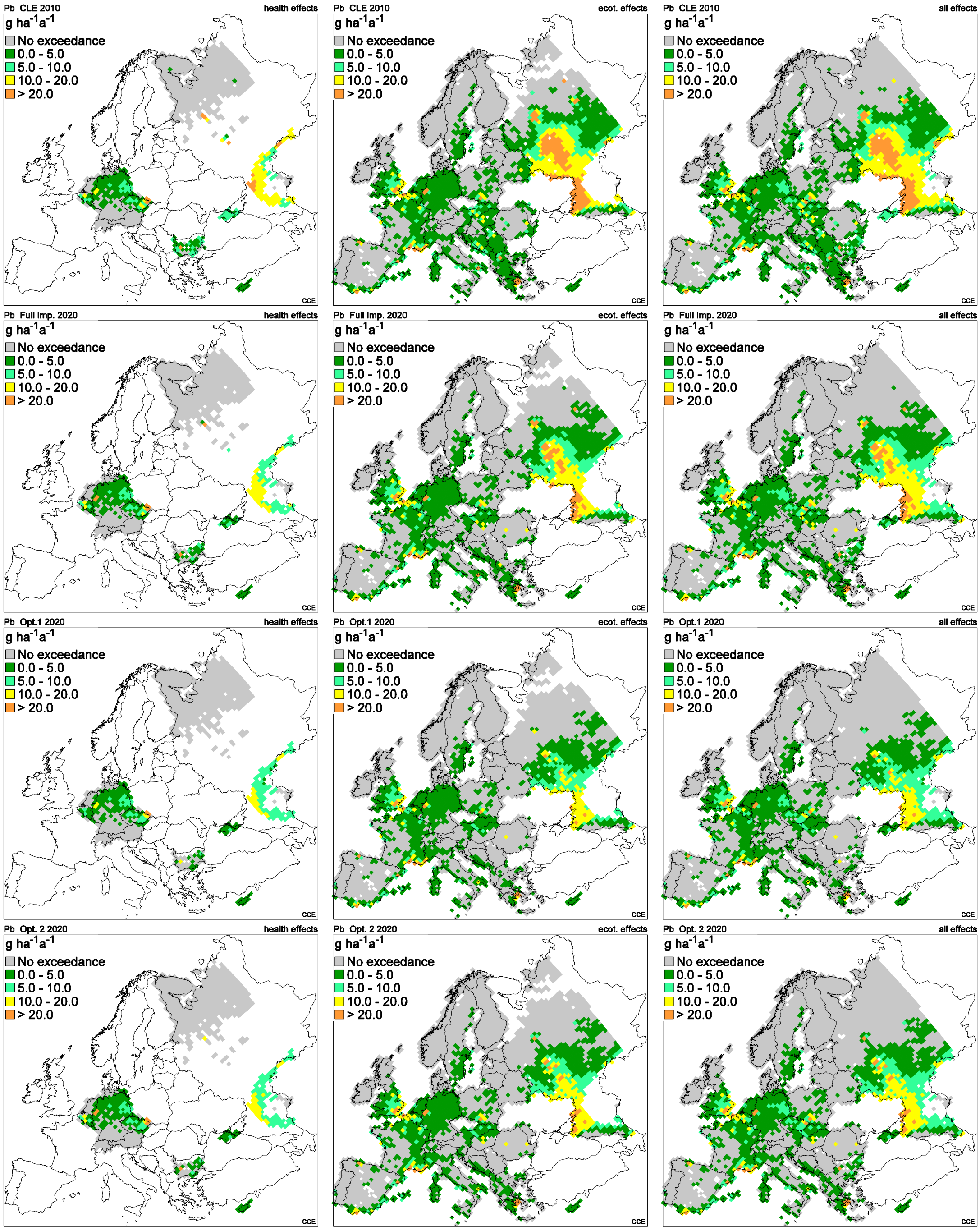
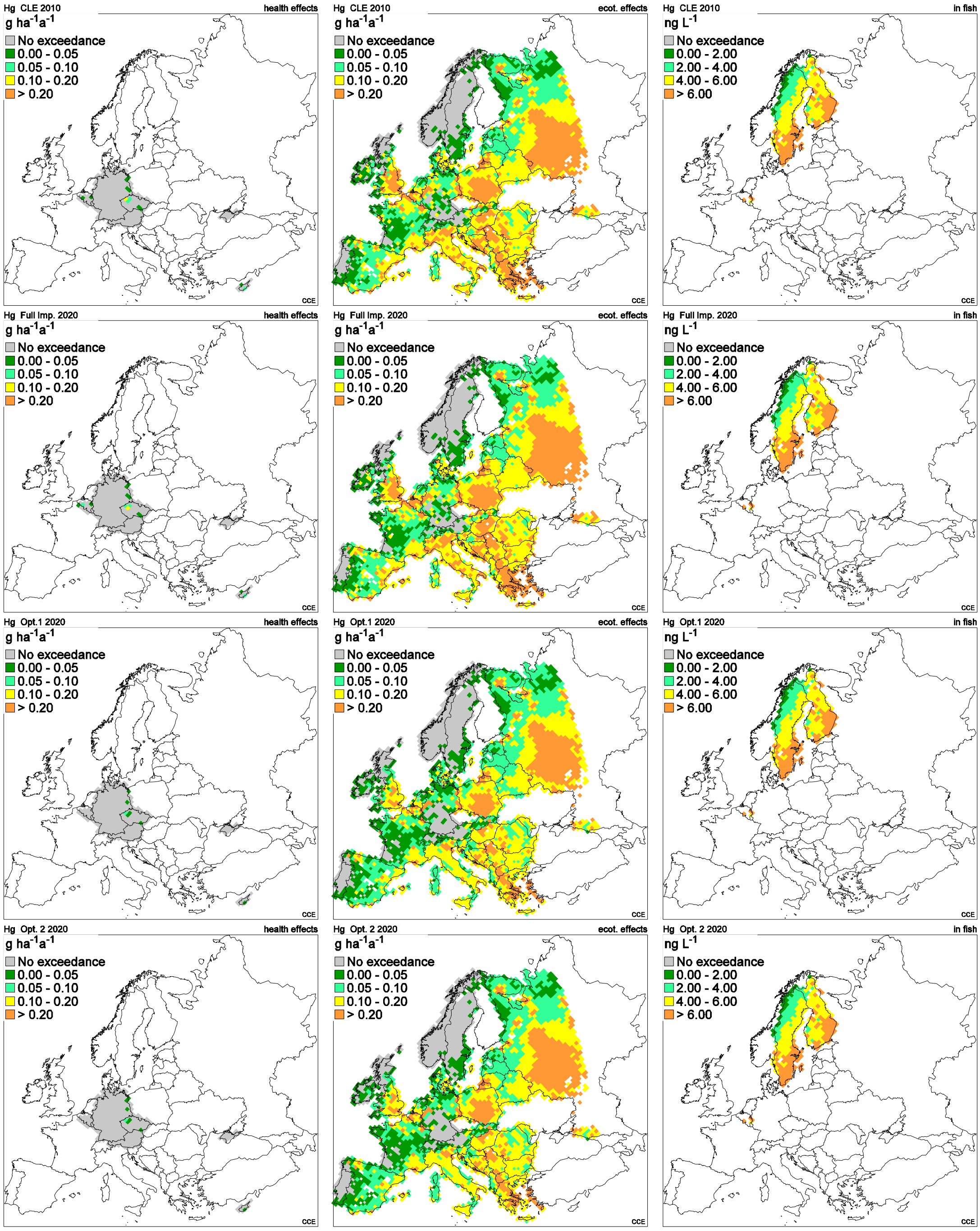


Figure 12: Exceedance (AAE) for Hg for three scenarios, with the present (CLE 2010) as a reference. The left column shows the exceedance for health effects (1 and 2), the middle for eco-toxicological effect (3 and 4), the rightmost column for unhealthy concentration in fish (effect 5).



Note:

A full report of this research project is to be published early next year in the 2010 Status Report of the Coordination Centre for Effects. In addition TNO will publish a separate report on the emissions of Cd, Hg and Pb under the various scenarios.

Annex: Emissions of cadmium, mercury and lead per country following different projection scenarios.

Table 1: Cadmium emission (kg) in UNECE Europe in 2010 and 2020 following different projection scenarios

ISO3	2010 CLE	2020 CLE	2020 FIHM	2020 Opt1	2020 Opt2
ALB	196	197	184	159	165
ARM	156	156	151	150	151
AUT	1219	1244	1244	1120	1244
AZE	2767	2767	2758	832	1348
BEL	1597	1918	1918	1738	1918
BGR	3511	3628	3628	2537	3628
BIH	1572	1468	647	429	488
BLR	2583	2590	1718	1069	1291
CHE	2892	2579	2579	2480	2579
CYP	1205	528	528	275	528
CZE	1134	1129	1129	931	1129
DEU	10293	10981	10981	9740	10981
DNK	747	941	941	845	941
ESP	17787	19415	19415	17298	19415
EST	687	494	494	279	494
FIN	1106	1099	1099	969	1099
FRA	9056	8646	8646	6570	8646
GBR	3368	3537	3537	3202	3537
GEO	265	265	255	155	182
GRC	2378	2521	2521	1943	2521
HRV	790	777	745	378	466
HUN	1484	2219	2219	1460	2219
IRL	626	618	618	482	618
ISL	85	98	98	76	82
ITA	8648	9167	9167	8643	9167
KAZ	22386	22386	13573	5493	6979
KGZ	433	433	346	328	333
LTU	408	459	459	252	459
LUX	55	64	64	64	64
LVA	592	587	587	363	587
MDA	327	325	325	275	289
MKD	9623	9286	4475	744	1227
MLT	617	617	617	617	617
NLD	1942	2059	2059	1772	2059
NOR	587	609	609	596	609
POL	39648	36160	36160	32971	36160
PRT	2350	2119	2119	1537	2119
ROM	2466	2530	2530	2293	2530
RUS	123849	143314	62448	26490	35305
SVK	3321	3623	3623	3178	3623
SVN	1320	1522	1522	1389	1522
SWE	607	494	494	431	494
TUR	17915	20764	10048	5668	6964
UKR	19093	19800	12744	9635	10900
YUG	8426	9408	3103	1314	1749
Grand Total	332117	355544	235127	159169	189426

Table 2: Mercury emission (kg) in UNECE Europe in 2010 and 2020 following different projection scenarios

ISO3	2010 CLE	2020 CLE	2020 FIHM	2020 Opt1	2020 Opt2
ALB	195	194	189	152	153
ARM	197	197	192	148	148
AUT	1054	1130	1130	761	772
AZE	1174	1174	1168	1009	1041
BEL	2737	3324	3323	2171	2195
BGR	1612	1722	1722	1104	1124
BIH	1841	1670	1559	1376	1429
BLR	741	741	695	301	305
CHE	1050	945	945	541	543
CYP	672	701	701	318	322
CZE	3922	3970	3970	2874	2932
DEU	9780	10144	10144	6999	7152
DNK	1119	1053	1053	863	876
ESP	10804	12338	12289	7456	7608
EST	656	628	628	597	615
FIN	812	846	846	604	618
FRA	6904	6063	6063	4843	4928
GBR	7190	6837	6808	5153	5225
GEO	305	305	297	223	225
GRC	7784	8657	8641	4266	4343
HRV	624	692	665	405	415
HUN	2829	3086	3086	1755	1772
IRL	858	969	959	507	512
ISL	106	109	96	61	63
ITA	10712	11246	11221	7194	7260
KAZ	19516	19516	18575	17180	17676
KGZ	732	732	705	596	604
LTU	431	445	445	299	306
LUX	290	315	315	112	113
LVA	30	36	36	35	36
MDA	137	126	126	108	112
MKD	1793	1597	1528	1256	1275
MLT	626	626	626	626	626
NLD	655	676	676	560	572
NOR	759	792	792	623	626
POL	15880	16089	16089	12931	13227
PRT	2758	2645	2645	1779	1812
ROM	4130	4099	4099	3513	3572
RUS	92713	117565	110165	95340	98828
SVK	2722	3301	3301	1683	1695
SVN	571	683	683	438	447
SWE	640	533	533	417	422
TUR	22337	30278	28249	13682	13943
UKR	7558	7741	6874	6228	6429
YUG	5343	5899	5495	4642	4823
Grand Total	255299	292438	280347	213728	219720

Table 3: National lead emission (kg) in UNECE Europe in 2010 and 2020 following different projection scenarios

ISO3	2010 CLE	2020 CLE	2020 FIHM	2020 Opt1	2020 Opt2
ALB	1340	1343	939	871	887
ARM	618	618	498	461	464
AUT	15336	16220	16220	13061	16220
AZE	7823	7823	7588	4229	5122
BEL	60549	71210	71210	55960	71210
BGR	65851	68345	68345	40590	68345
BIH	91102	27326	7457	2979	4180
BLR	58992	58993	41680	14404	18097
CHE	19877	19842	19842	19014	19842
CYP	977	952	952	842	952
CZE	44065	42689	42689	28256	42689
DEU	289850	311065	311065	247197	311065
DNK	6166	5894	5894	4213	5894
ESP	278059	322493	322493	257592	322493
EST	11193	9658	9658	5985	9658
FIN	21210	21835	21835	16777	21835
FRA	109027	111886	111886	85770	111886
GBR	71134	72017	72017	55125	72017
GEO	14755	14755	14455	14249	14304
GRC	12117	13130	13130	11478	13130
HRV	9184	10793	10481	4747	5316
HUN	34561	39393	39393	26962	39393
IRL	14779	12080	12080	11519	12080
ISL	197	205	204	142	158
ITA	273719	289441	289441	228764	289441
KAZ	650982	650982	369683	176102	219523
KGZ	8445	8445	4372	3478	3712
LTU	6797	6898	6898	5355	6898
LUX	5174	6099	6099	6090	6099
LVA	1170	1729	1729	1321	1729
MDA	1112	914	914	868	879
MKD	59949	40900	23667	4123	6568
MLT	848	848	848	848	848
NLD	39352	40543	40543	33242	40543
NOR	7041	7355	7355	6802	7355
POL	276459	262308	262308	213229	262308
PRT	22080	21060	21060	15365	21060
ROM	77378	83692	83692	67272	83692
RUS	2015655	2450767	998831	353183	530920
SVK	27269	27555	27555	19441	27555
SVN	14382	15372	15372	14904	15372
SWE	16016	15245	15245	13217	15245
TUR	187079	203004	128082	73533	88239
UKR	785004	804164	436643	214994	288958
YUG	193796	32527	14845	5029	7381
Grand Total	5908469	6230414	3977194	2379582	3111562