

## ***Chapter 7***

### **Heavy metals**

Authors: Ilia Ilyin, Torun Berg, Sergey Dutchak, Jozef Pacyna

#### **7.1 Introduction**

Heavy metals are naturally occurring elements, and are present in varying concentrations in all ecosystems. There is a huge number of heavy metals. They are found in elemental form and in a variety of other chemical compounds. Those that are volatile and those that become attached to fine particles can be widely transported on very large scales. Each form or compound has different properties which also affect what happens to it in food web, and how toxic it is. Human activities have drastically changed the biochemical cycles and balance of some heavy metals. Between 1850 and 1990, production of copper, lead and zinc increased 10-fold (Nriagu 1995; CACAR 1996). The main anthropogenic sources of heavy metals are various industrial processes, mining, foundries, smelters, combustion of fossil fuel and gasoline, and waste incinerators. The major heavy metals of concern to EMEP are Hg, Cd and Pb, because they are the most toxic and have known serious effects on e.g. human health. Environmental exposure to high concentrations of heavy metals has been linked with e.g. various cancers and kidney damage. There are considerably more measurements data on Hg, Cd and Pb in Europe than for other metals.

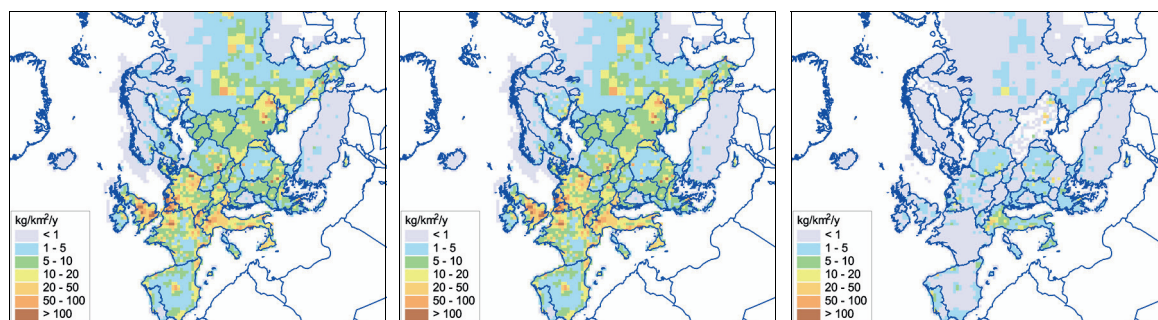
#### **7.2 Emissions of heavy metals**

The UNECE 1998 Aarhus Protocol on Heavy Metals currently has 36 signatories and 21 ratifications (May 11, 2004) and entered into force by the end of 2003. Complete and accurate data on heavy metal emissions are thus increasingly important within the CLRTAP convention. In particular, reliable emission data are needed to assess further measures to reduce environmental exposure to heavy metals (HMs) as well as to understand and predict source-receptor relationships of heavy metals on a regional scale. Three particularly harmful metals are targeted in the protocol, namely cadmium (Cd), lead (Pb) and mercury (Hg). In accordance with this agreement, parties will have to reduce their emissions for these three heavy metals below their levels in 1990 (or an alternative year between 1985 and 1995). The Protocol further aims to cut emissions from various industrial sources, selected combustion processes as well as waste incineration. It furthermore lays down stringent limit values for emissions from stationary sources and suggests best available techniques (BAT) for these sources, such as special filters or scrubbers for combustion sources or mercury-free processes.

The emission data presented herein is based on official submissions to UNECE (e.g. Vestreng 2003) as well as expert estimates (Olendrzynski et al 1996; Berdowski et al 1997; Pacyna and Pacyna 2002).

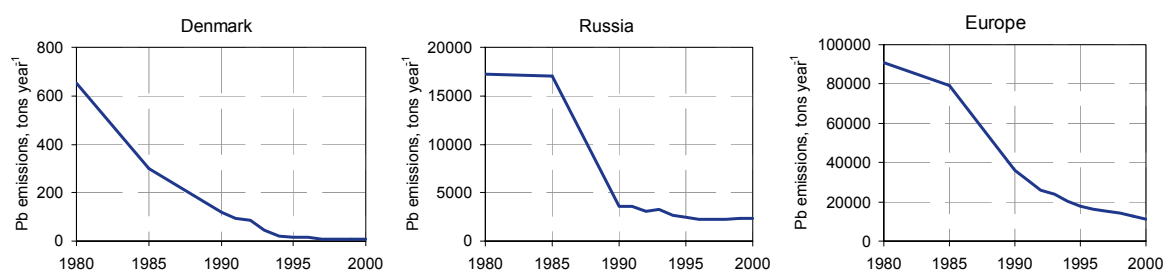
### 7.2.1 Emissions of lead

*Gasoline lead additives have been the key source of lead to the European atmosphere over the last decades. Lead from road traffic still remains the key source with non-ferrous metal manufacturing, stationary fuel combustion as well as iron and steel production as additional significant source categories.*



**Figure 1.** Atmospheric emissions of lead in Europe in 1980 (left), 1990 (middle) and 2000 (right) in kg km<sup>-2</sup> year<sup>-1</sup>.

Lead (Pb) provides an interesting and important example of a heavy metal that has experienced significant changes in anthropogenic atmospheric emissions over the last decades (Pacyna and Pacyna, 2000). The Protocol requires Parties to phase out leaded petrol, and the significant changes in temporal and spatial patterns from 1980 to 2000 are to a large extent influenced by the substantial reductions in use of gasoline lead additives. It is evident that these changes in emissions also have had a marked impact on the transboundary air pollution of lead in Europe during the same period (von Storch et al. 2003).

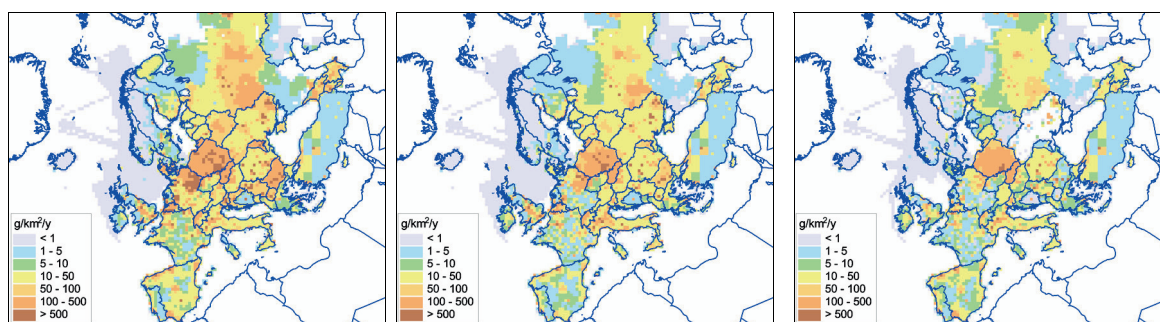


**Figure 2.** Temporal trend in emissions of lead in Europe (left), Russia (middle) and Denmark (right) from 1980 to 2000 in tons year<sup>-1</sup>.

Still, there are marked differences in the temporal trend in emissions of lead in various countries across Europe. For example, a continued use of lead in gasoline in Russia over the last decade has limited further steep reductions during the 1990s (von Storch et al 2003).

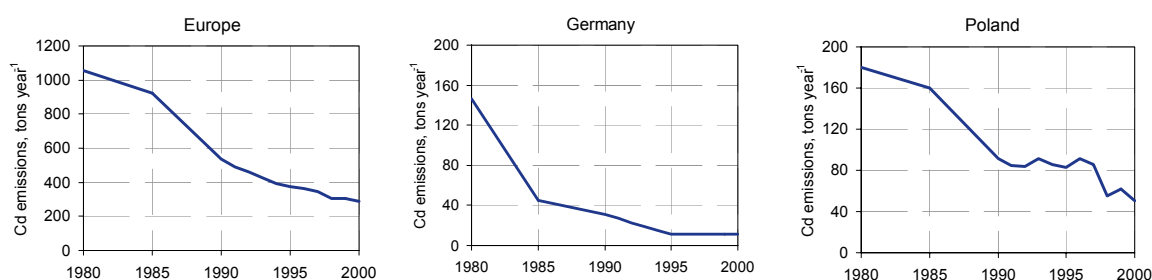
## 7.2.2 Emissions of cadmium

*Atmospheric cadmium may originate from multiple sources. Of key significance are various combustion processes based on fossil fuels (in particular coal and oil), as well as various processes in the pyrometallurgical non-ferrous metal industries.*



**Figure 3.** Atmospheric emissions of cadmium in Europe in 1980 (left), 1990 (middle) and 2000 (right) in  $\text{g km}^{-2} \text{year}^{-1}$ .

Figure 2 displays the spatial pattern of cadmium emissions across Europe in 1980, 1990 and 2000. As for the other heavy metals discussed, there are significant differences in the spatial pattern. The situation around 1980 reflects cadmium emission in heavily industrialized zones of Europe as well as regions utilizing coal as an important source of energy.

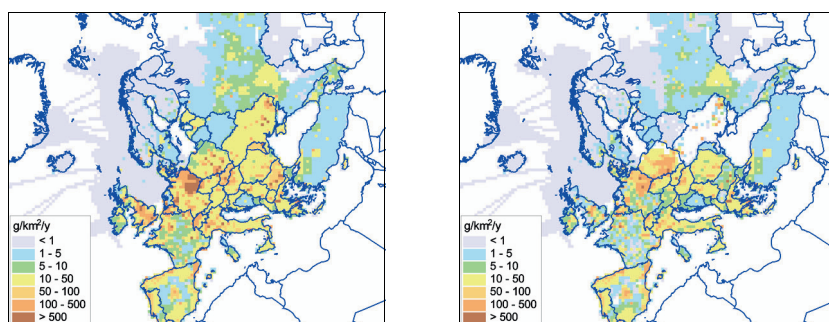


**Figure 4.** Temporal trend in emissions of cadmium in Europe (left), Germany (middle) and Poland (right) from 1980 to 2000 in  $\text{tons year}^{-1}$ .

By the year 2000, there had been a 63% reduction in emissions of cadmium in Europe as compared to 1980 (Figure 4). Certain industrialized countries relying on coal, such as Germany, have seen substantial reductions in atmospheric emissions (92%).

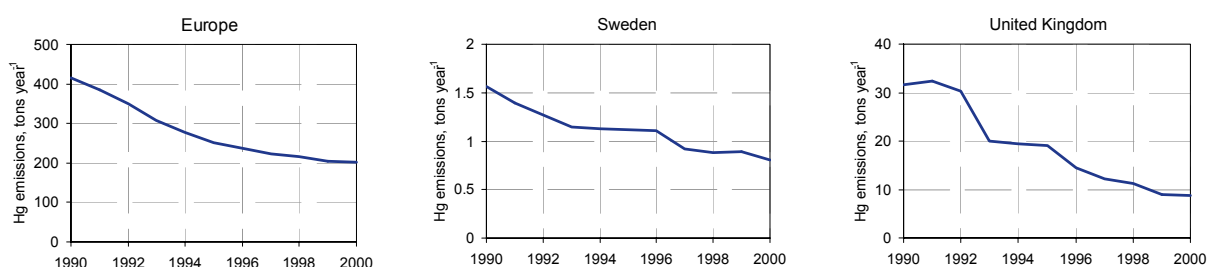
### 7.2.3 Emissions of mercury

*Atmospheric levels of mercury are affected by both natural and anthropogenic sources, although anthropogenic emissions are suggested to be the largest source in Europe. The most important anthropogenic sources of mercury are the combustion of fuels and in particular coal. Additional anthropogenic sources of key significance are chlor-alkali production, cement production and waste incineration.*



**Figure 5.** Atmospheric emissions of mercury in Europe in 1990 (left) and 2000 (right) in  $\text{g km}^{-2} \text{year}^{-1}$ .

Much effort has been devoted to understand and predict the sources and emissions of mercury (Hg) in various research projects over the last few years. This has greatly facilitated frequent updates of European and global scale atmospheric emission inventories for Hg and its associated forms (Pacyna and Pacyna 2002; Pacyna et al 2001). Figure 5 presents estimated emissions of mercury in Europe in 1990 and 2000.



**Figure 6.** Temporal trend in emissions of mercury in Europe (left), Sweden (middle) and United Kingdom (right) from 1990 to 2000 in  $\text{tons year}^{-1}$ .

The data contained in Figure 6 suggest that there has been a 52% reduction in the emissions of Hg in Europe from 1990 to 2000. The emissions of mercury from various combustion processes have seen a limited reduction, whereas significant decreases are suggested from industrial sources. Of key importance has been the reduction of mercury emissions from the production of chlor-alkali plants employing the Hg cell process (Pacyna et al 2001). It should be mentioned that the Protocol additionally introduces measures to lower heavy metal emissions from products, such as mercury in batteries, and proposes the introduction of management measures for other mercury-containing products.

### 7.2.4 Discussion

The available information on emissions of heavy metals is generally considered more reliable and complete as compared to the persistent organic pollutants (see chapter 8.2), although significant gaps in knowledge remain (e.g. relative importance of natural sources, chemical speciation of emissions). Table 1 presents official submissions of national HM emission totals to EMEP during the period from 1996 to 2001 (Vestreng, 2003). For some countries, the available data at EMEP include historical emissions dating back to 1980 as well as emission projections up to year 2020.

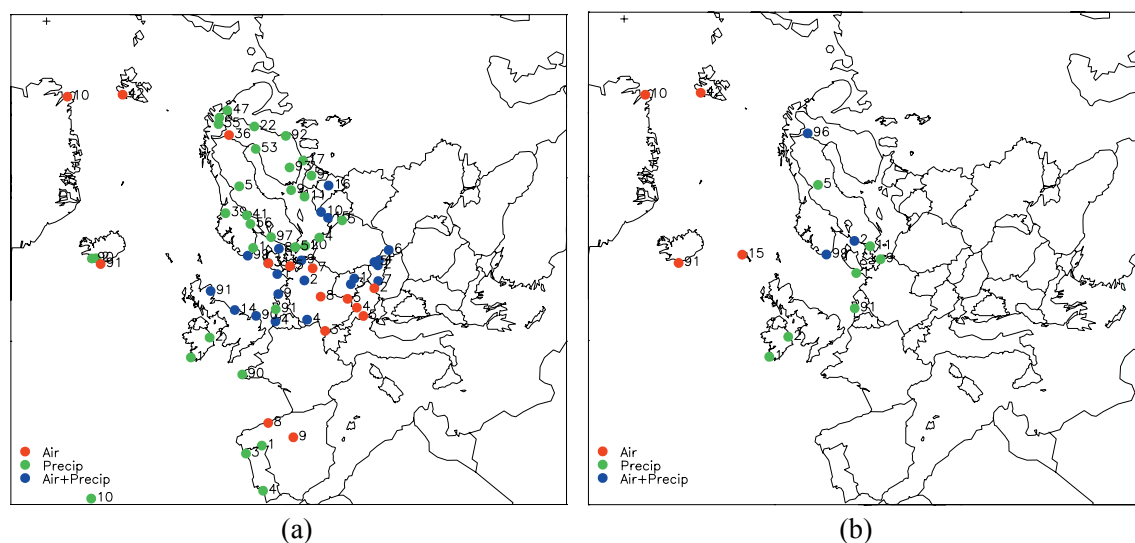
**Table 1.** Official submissions of HM emission totals to EMEP MSC-W from 1996 to 2001 among the 49 parties to the convention (Vestreng, 2003).

	1996	1997	1998	1999	2000	2001
Lead	31	29	30	29	28	23
Cadmium	28	26	27	26	26	22
Mercury	29	26	27	26	26	22
Chromium	22	20	21	20	20	18
Copper	21	20	21	19	20	19
Nickel	21	19	20	18	19	17
Selenium	17	15	16	14	14	14
Zinc	22	18	22	19	20	18

Still, the data on HM emissions reported to EMEP are generally considered incomplete in terms of spatial and temporal coverage, as well as sector coverage. Therefore, modellers are often utilising so-called expert estimates of HM emissions to provide more complete input to their models. A number of studies have been devoted to European emissions of HMs over the last two decades (e.g. Pacyna, 1983; Axenfeld et al 1989; 1991; Berdowski et al 1994;1997; Olendrzynski et al 1996; Pacyna et al 2001) whilst others investigations have had a global approach (e.g. Nriagu and Pacyna, 1988; Pacyna and Pacyna 2001/2002; Pacyna et al 2003).

## 7.3. Heavy metal pollution levels

Assessment of environmental pollution can be carried out by means of monitoring and modelling. In order to realize integrated view of pollution EMEP combines these two approaches. Heavy metals were included in EMEP's monitoring program in 1999. However, earlier data have been available and collected, and the EMEP database thus also includes older data, even back to 1991 for a few sites [www.nilu.no/projects/ccc]. A number of countries have been reporting heavy metals within the EMEP area in connection with different national and international programmers such as HELCOM, AMAP and OSPAR. The number of stations has been increasing, and in 2001 it was 69 measurement sites altogether. Among them 22 sites measured heavy metals in both in air and in precipitation [Figure 7a]. Mercury was measured at 15 sites [Figure 7b].



**Figure 7.** Measurement network of heavy metals, 2001. (a): lead and cadmium; (b) mercury

Measurement network covers only part of EMEP region. In order to provide coverage for the entire Europe, modelling tools are used. Models can also provide additional information on transboundary depositions. For the needs of European assessment Eulerian three-dimensional model of atmospheric transport of heavy metals was used. The model was described in the General Introduction. The model output includes deposition and concentration fields, transboundary transport, and long-term trends of pollution levels. Additionally, following the request of the Working Group on Effects (WGE), ecosystem –dependent depositions are evaluated.

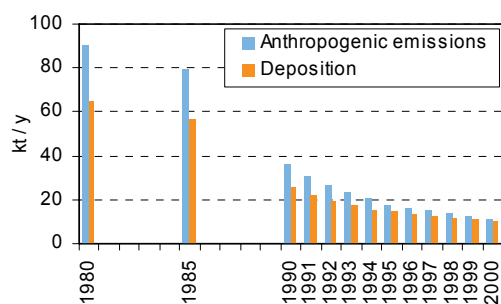
The following chapter provides an overview of heavy metals (lead, cadmium and mercury) pollution levels in Europe in the period from 1980 to 2000. The review of mercury levels is made only for the period from 1990 to 2000 because of lack of emission data prior to 1990.

### 7.3.1 Pollution levels of lead

In nature lead is a ubiquitous, non-essential element and toxic. Its natural concentrations are not very high. Lead concentrations are locally and regionally, much higher than they were. Some lead is taken up by plants and animals and may affect brain and nerve tissue.

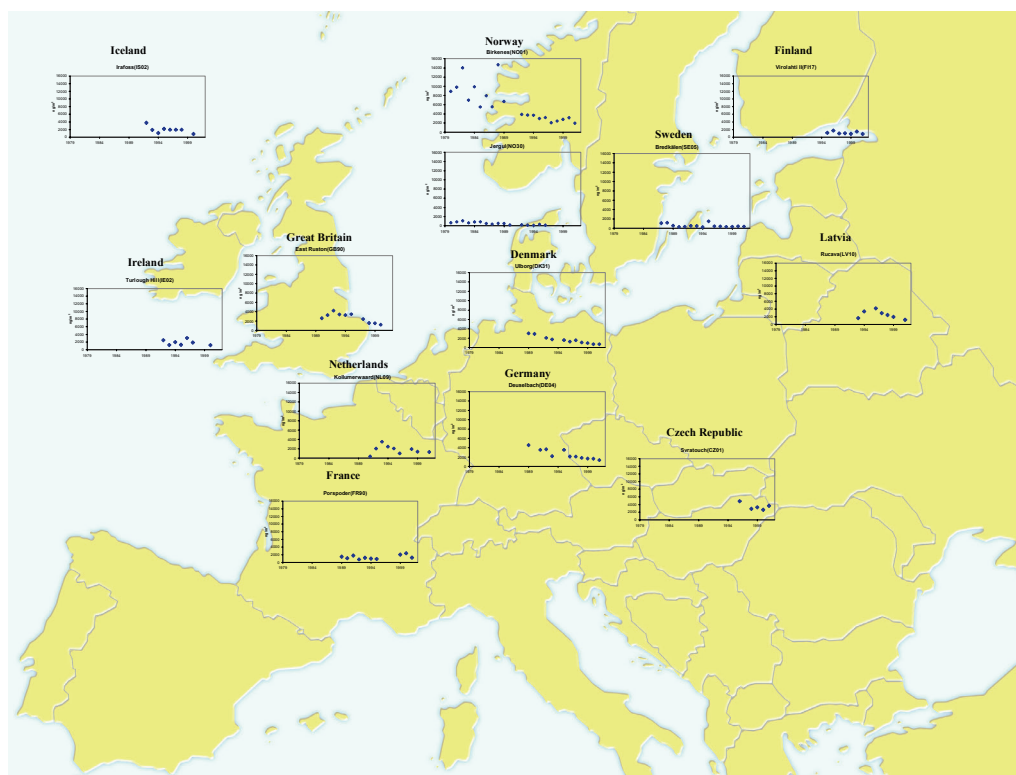
#### *Trends in annual means 1980-2000*

Emissions and depositions of lead in Europe decreased considerably from 1980 to 2000 (Figure 8). Lead emissions have dropped down about 8 times, and depositions – more than 6 times. The highest reduction of emissions and depositions took place between 1985 and 1990. The rate of deposition decline was less than that of emissions due to the impact of natural emissions, re-emission and the contribution of sources located outside Europe.



**Figure 8.** Trends of lead emissions and depositions in Europe for 1980-2000.

### Lead- Trends in Europe 1980-2001

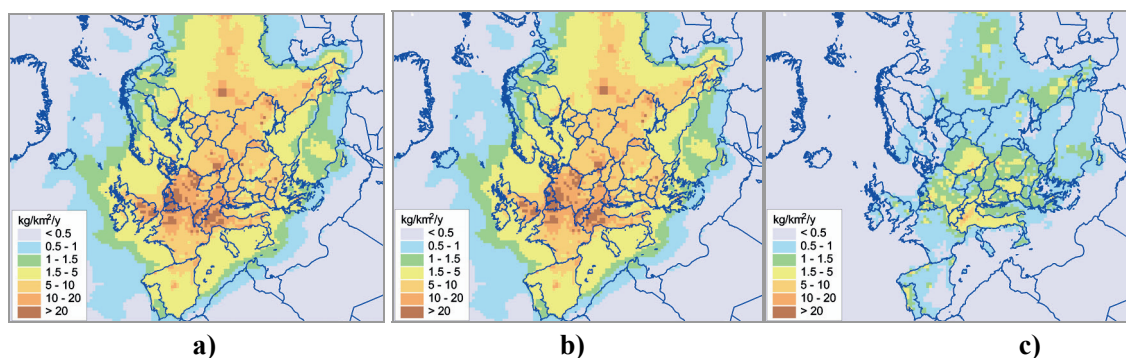


**Figure 9.** Trends for lead deposition between 1980 and 2001 at a number of European EMEP sites with long data series.

The negative trends simulated by the models are also confirmed at some of the measurement sites with longest time series, e.g. NO<sub>3</sub> (Jergul) which shows the highest decrease in the eighties and a much more moderate decrease in the nineties (Figure 9). At most of monitoring stations wet depositions of lead were also decreasing.



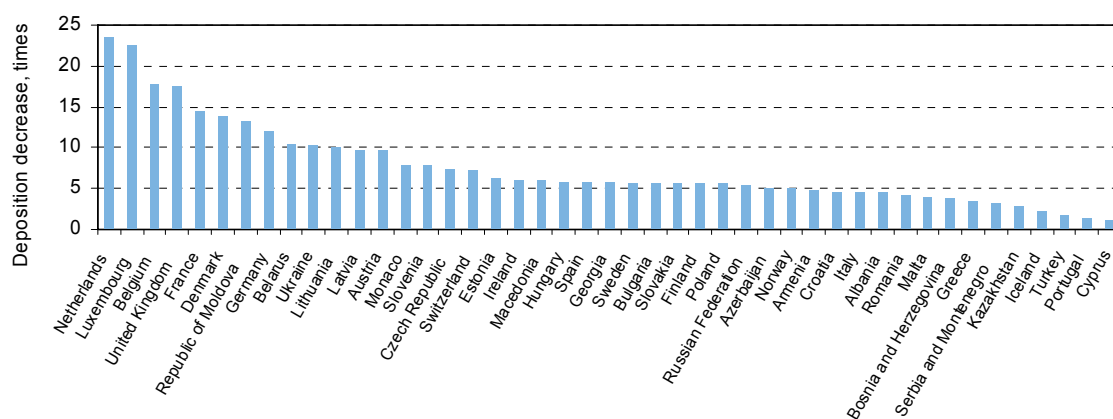
Deposition fluxes of lead over the major part of Europe exceeded 5 kg/km<sup>2</sup>/y in 1980 (Figure 10). In some countries (e.g. Germany, Austria, the Netherlands) deposition fluxes were as a rule higher than 10 kg/km<sup>2</sup>/y. In 2000 deposition fluxes were below 1.5 kg/km<sup>2</sup>/y in most part of Europe.



**Figure 10.** Spatial distribution of lead deposition fluxes 1980(a) , 1990 (b) and 2000 (c).

Spatial pattern of air concentrations of lead is similar to that of depositions. Obviously, the highest concentrations occur in regions with high emissions. In 1980 concentrations varied between 5 and 70 ng/m<sup>3</sup>. By 2000 typical range was 2 - 12 ng/m<sup>3</sup>.

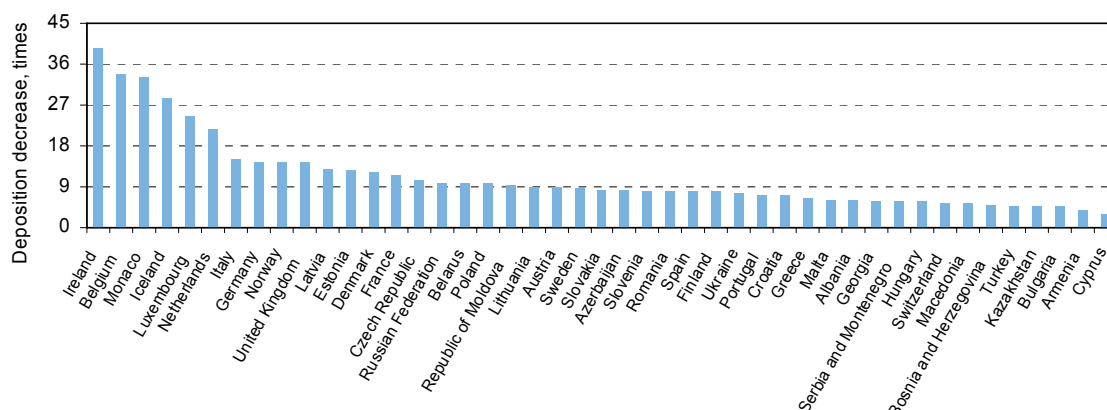
In each country the rate of deposition decline was different during the period from 1980 to 2000 (Figure 11). The highest decrease – almost 24 times – took place in the Netherlands. In most countries this value ranges between 5 and 15 times. The reduction of the pollution levels results from a decline of national emissions and transboundary transport.



**Figure 11.** Decrease of lead total depositions between 1980 and 2000 in different European countries.

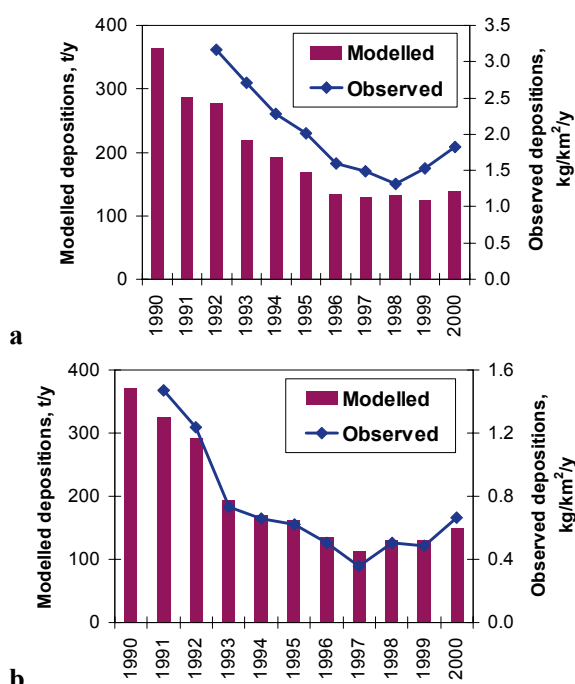
Emission reduction in European countries caused the decline of heavy metal levels and, in particular, of transboundary depositions. Since 1980 absolute values of transboundary depositions have decreased to a great extent. For example, in Cyprus this drop made up about 3 times, in Ireland – almost 40 times (Figure 12). For most countries transboundary depositions cut down 5 – 15 times.





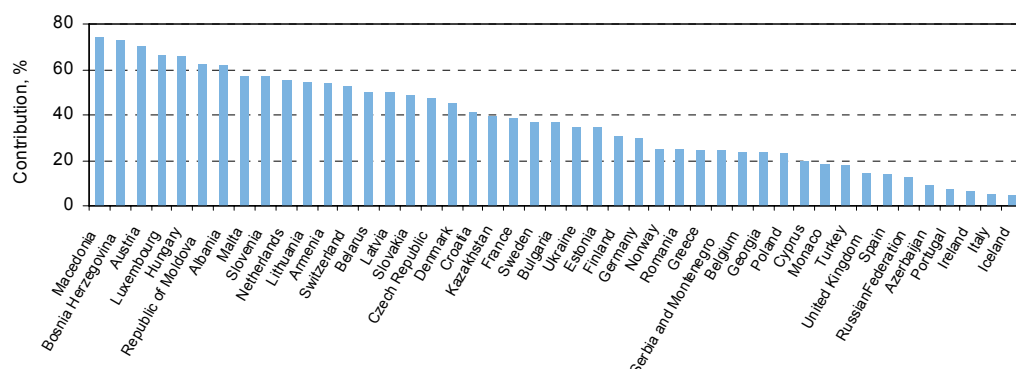
**Figure 12.** Decrease of lead depositions from transboundary transport between 1980 and 2000 in different European countries.

Rate of deposition decrease, estimated by the model, is confirmed by EMEP monitoring data. For example, variations of modelled depositions to Finland and Norway are well correlated with averaged over country measured wet depositions (Figure 13).



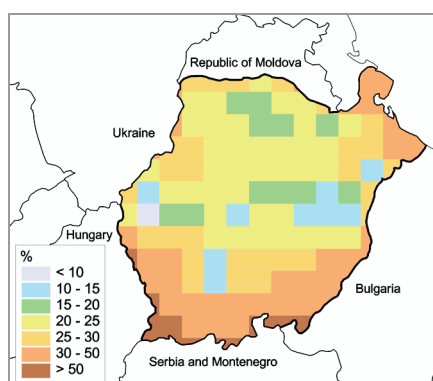
**Figure 13.** Modelled total depositions to a country and averaged over country wet deposition flux of lead (a) – Norway, (b) - Finland

Nevertheless, the role of transboundary transport in air pollution of countries remains significant. Transboundary depositions vary essentially among European countries (Figure 14). On the average this contribution amounted to 40%, ranging from about 75% (Macedonia) to 5% (Iceland) in 2000.



**Figure 14.** Contribution of transboundary pollution to total depositions in the European countries.

The contribution of transboundary transport is non-uniformly distributed over countries. An example of this distribution is given for Romania (Figure 15), where the contribution of transboundary depositions over the whole country amounted to 25% in 2000 (Figure 5). Regions neighbouring the countries with powerful emission sources (Bulgaria, Serbia and Montenegro) are most subjected to external anthropogenic sources. The contribution of transboundary depositions along the state borders is more than 50%. The input of transboundary transport is the least in central regions and regions with significant national emissions.



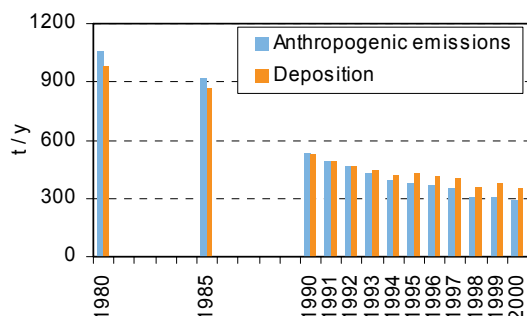
**Figure 15.** Contribution of transboundary depositions of lead in Romania in 2000

More detailed information about source-receptor relationships for each country one can see in EMEP/MSCE reports [Ilyin et al., 2002, 2003] or Internet: [www.msceast.org](http://www.msceast.org).

### 7.3.2 Pollution levels of cadmium

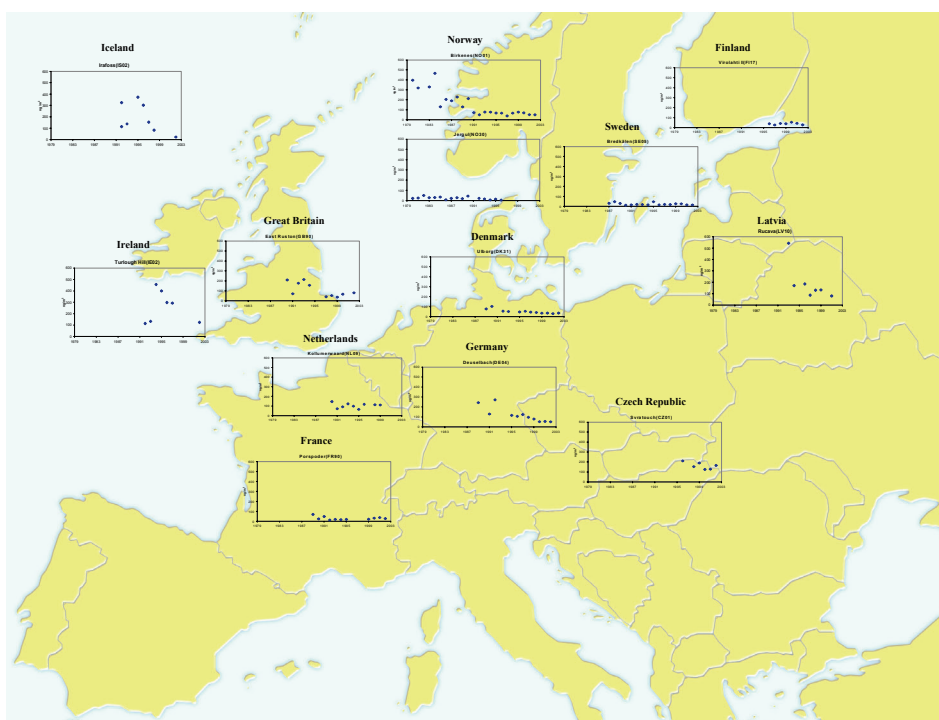
Cadmium is not essential for plants, animals and human beings, but has toxic effects. It can be taken up directly from air and water, and accumulates in living organisms. In addition to atmospheric long-range transport and the ubiquitous distribution of cadmium, emissions lead to local and regional pollution of soil and river sediments.

Cadmium emissions in Europe decreased about 4 times, and depositions – almost 3 times for the period from 1980 to 2000 (Figure 16). The most significant decrease of pollution levels was in the period from 1985 to 1990.



**Figure 16.** Trends of cadmium emissions and depositions in Europe for 1980-2000.

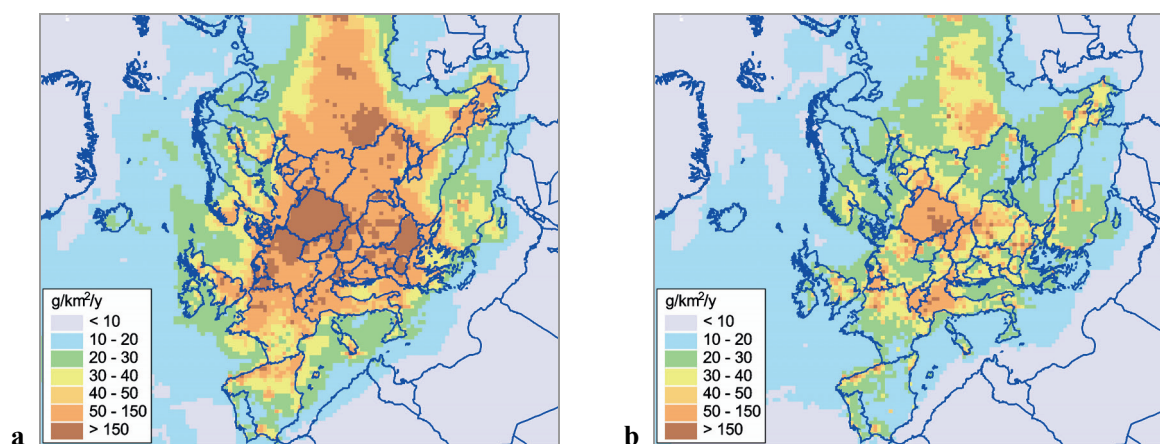
### Cadmium- Trends in Europe 1980-2002



**Figure 17.** Trends for cadmium deposition between 1980 and 2002 at a number of European EMEP sites with long data series.

As for lead, the negative trends observed by the models are also confirmed at some of the measurement sites with longest time series, e.g. NO30 (Jergul) which shows the highest decrease in the eighties and a much more moderate decrease in the nineties (Figure 17). Other sites also demonstrate decrease of wet depositions of cadmium.

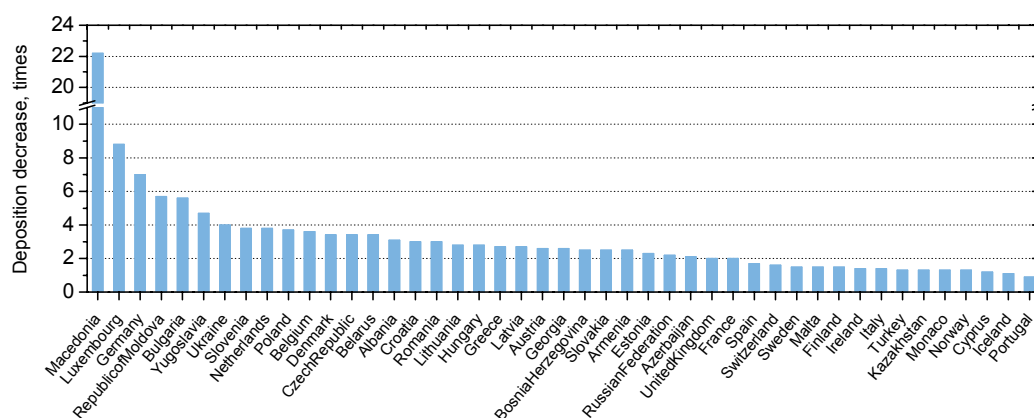
Over most part of Europe deposition fluxes varied from 30 g/km<sup>2</sup>/y to 150 g/km<sup>2</sup>/y in 1980 (Figure 18). In some countries (Poland, Germany, Bulgaria) deposition fluxes were even higher. The fluxes have reduced substantially nearly in all regions of Europe by 2000 and have reached 20 – 50 g/km<sup>2</sup>/y.



**Figure 18.** Spatial distribution of cadmium deposition fluxes, 1980 (a) and 2000 (b)

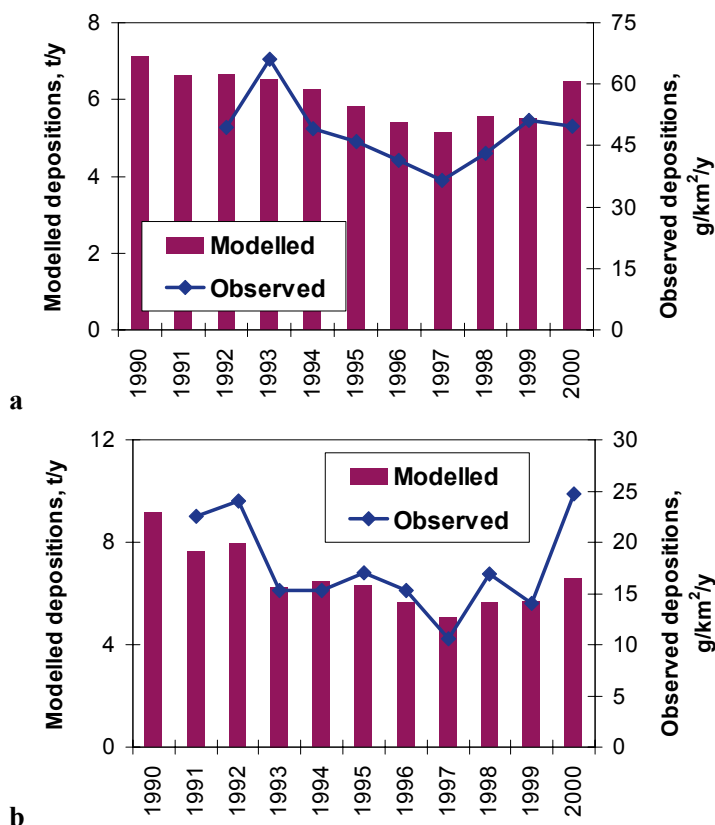
Similar to depositions, cadmium concentrations in air declined substantially. Over major part of Europe the concentrations ranged 0.1 – 0.7 ng/m<sup>3</sup> in 1980. In 2000 concentrations typically laid between 0.07 and 0.25 ng/m<sup>3</sup>.

Variation of depositions in each European country for the considered period is demonstrated in Figure 19. In the majority of countries depositions diminished from 1.5 to 5 times. In some countries, like Macedonia, Luxembourg or Germany, the decrease was more significant. The reduction of cadmium depositions to countries, compared to lead, was smaller mainly because of smaller decline of the emissions.



**Figure 19.** Decrease of cadmium total depositions for 1980 – 2000.

Magnitude of the decrease of cadmium depositions in European countries is comparable with that derived from results of monitoring. Similar to lead, modelled cadmium total depositions to countries generally capture observed variation of measured wet depositions. Examples of this comparison are given for Norway and Finland (Figure 20).

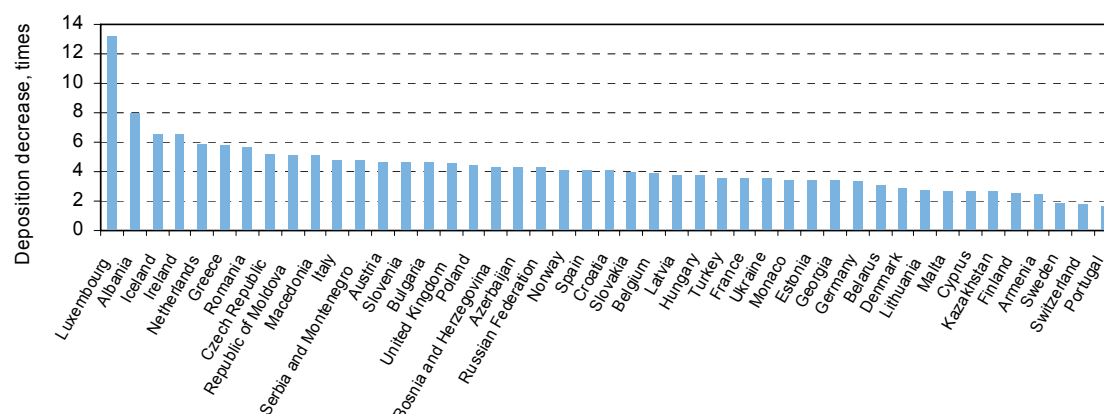


**Figure 20.** Modelled total depositions to a country and averaged over country wet deposition flux of cadmium (a) – Norway, (b) - Finland

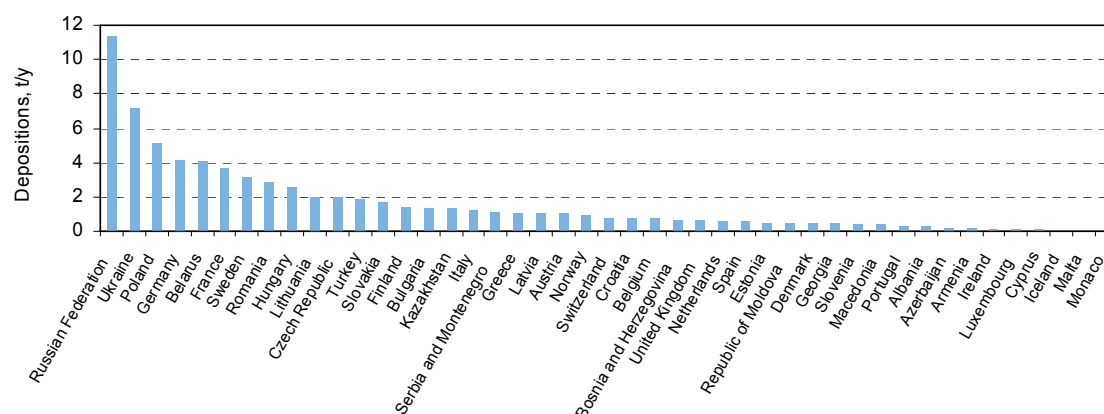
A significant portion of cadmium total atmospheric depositions in European countries is caused by transboundary transport. Transboundary depositions contributed around 30% to total depositions on the average in 2000. Maximum contribution (55%) was obtained for Lithuania, and the lowest (2%) – for Iceland.

Depositions caused by transboundary transport of cadmium have declined since 1980 (Figure 21). In Luxembourg the decrease of depositions from external sources was highest (about 13 times). Over most countries the decrease ranges from 3 to 6 times.

In spite of the decline, the role of transboundary transport of cadmium remains significant in Europe. For example, total depositions of cadmium from transboundary sources to Russia amounted to 11 t/y, to the Ukraine – 7 t/y and to Poland – 5 t/y in 2000 (Figure 22).



**Figure 21.** Decrease of cadmium depositions from transboundary transport for 1980 – 2000.



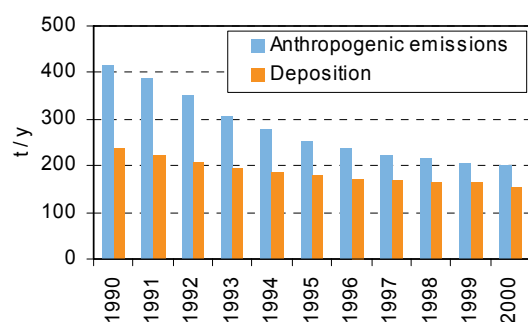
**Figure 22.** Total cadmium depositions from external anthropogenic sources.

### 7.3.3 Pollution levels of mercury

Mercury is a toxic environmental pollutant that is among the most highly bioconcentrated metals in the human food chain. Once emitted, mercury may be deposited by dry and wet processes to environmental surfaces. In aqueous systems, mercury is methylated, incorporated into microorganisms, and bioaccumulated through the food chain where human exposure occurs.

#### *Trends in annual means 1980-2000*

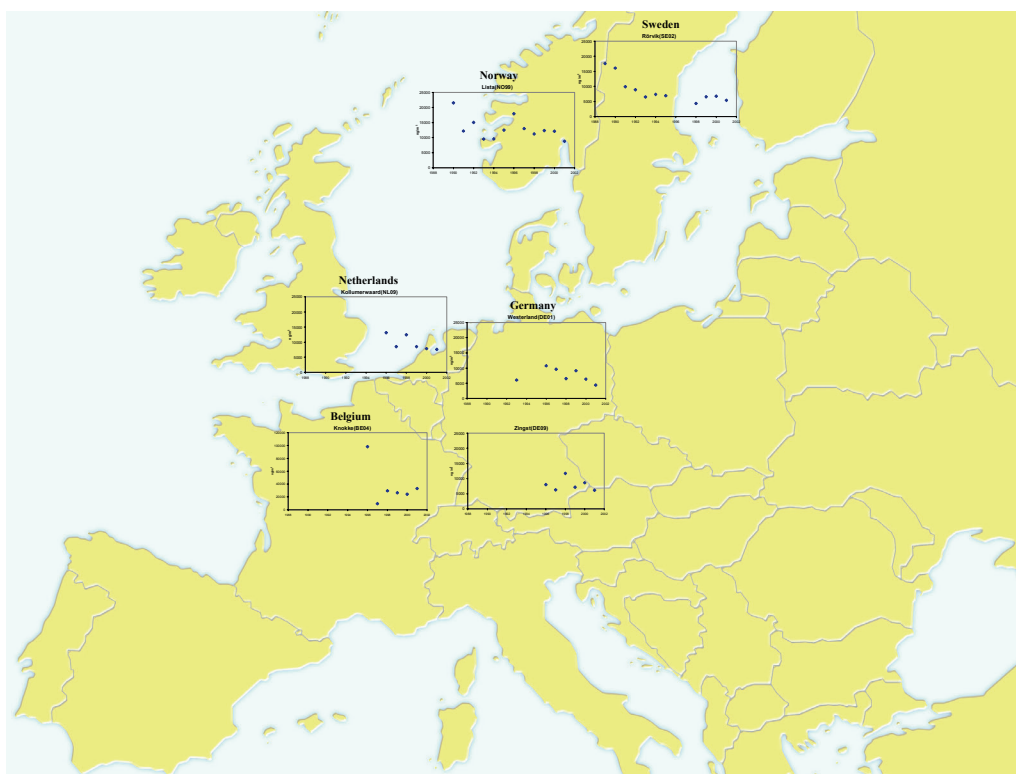
For the period from 1990 to 2000 mercury anthropogenic emissions in Europe were reduced by half and depositions decreased 1.5 times. A significant fraction of mercury depositions is caused by natural, global anthropogenic sources and re-emission. Deposition decline rate is less than that of anthropogenic emissions (Figure 23).



**Figure 23.** Trends of mercury emissions and depositions in Europe for 1990-2000.

A few stations have measured mercury in wet deposition (Figure 24). The Swedish station SE002 has the longest time series and confirm the emission and modelled data.

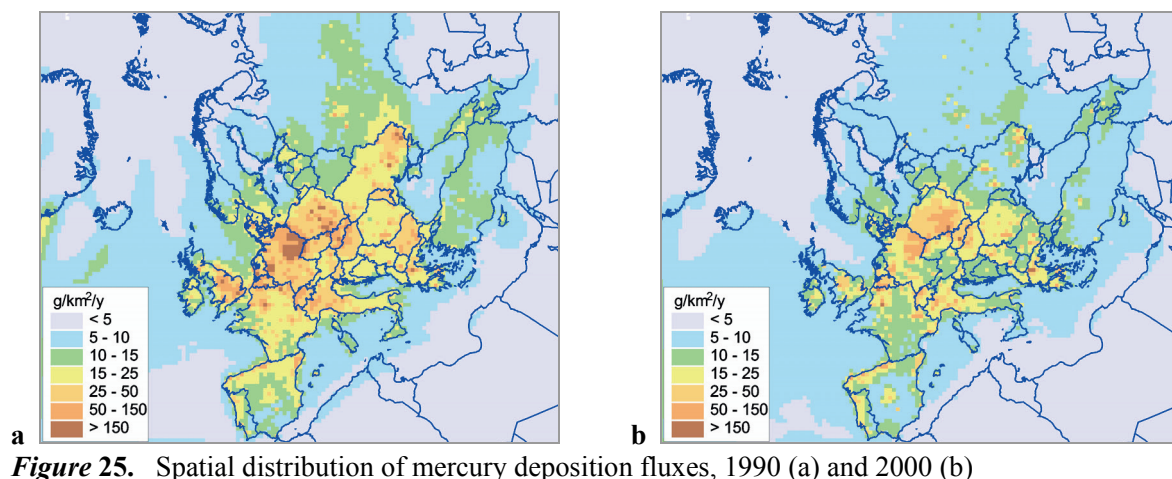
### Mercury- Trends in Europe 1989-2001



**Figure 24.** Trends for cadmium deposition between 1980 and 2001 at a number of European EMEP sites with long data series.



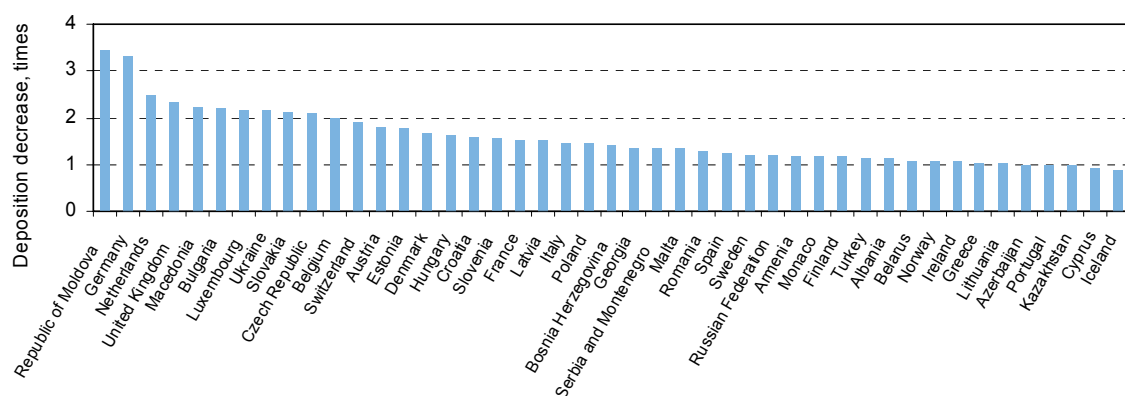
Changes in mercury pollution levels were overviewed for the period from 1990 to 2000. During this period spatial pattern of mercury depositions changed significantly (Figure 25). In 1990 deposition fluxes mainly ranged from 8 to 40 g/km<sup>2</sup>/y over Europe. Relatively high levels of deposition fluxes took place in Germany, Poland, the United Kingdom and some Balkan countries. Deposition fluxes have reduced almost in all regions of Europe by 2000, ranging from 8 to 25 g/km<sup>2</sup>/y over the most part of Europe.



**Figure 25.** Spatial distribution of mercury deposition fluxes, 1990 (a) and 2000 (b)

In 1990 concentrations of mercury in Europe varied between 1.7 - 3 ng/m<sup>3</sup>. In 2000 the concentrations were somewhat reduced compared to 1990. Relatively little reduction of concentrations (about 15 % on average) is explained mainly by global nature of mercury atmospheric transport.

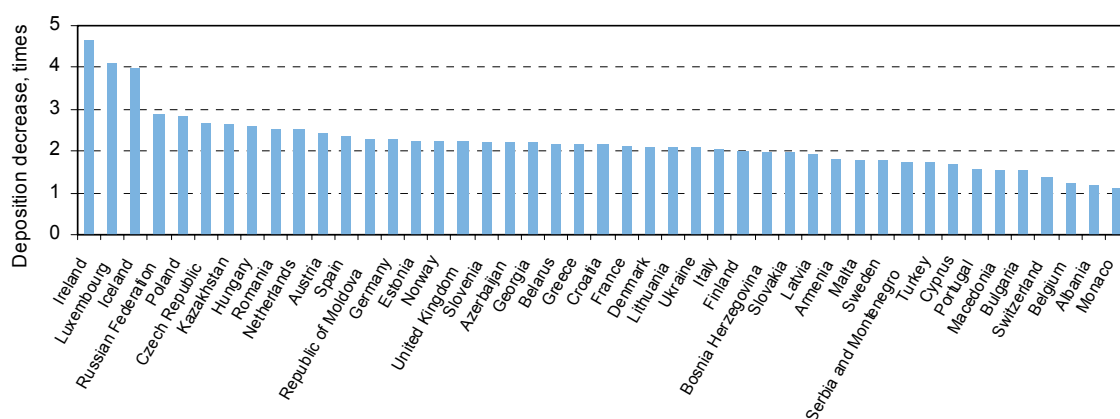
Due to different rate of emission reduction, rate of deposition decline varies from country to country (Figure 26). In the majority of countries depositions cut down 1.2 – 2.5 times. The highest deposition decline is noted in Republic of Moldova and in Germany (3.5 times). Some countries are characterized by a negligible deposition decrease or even increase. This is connected with a low rate of emission reduction in these and neighbouring countries and meteorological variability.



**Figure 26.** Decrease of mercury total depositions for 1990 – 2000.

Average contribution of mercury depositions from external anthropogenic sources to total depositions in European countries amounted to 20% in 2000. However, this contribution is different for different countries. The highest input of external sources (almost 50%) is made to the Netherlands, the lowest (1%) – to Iceland.

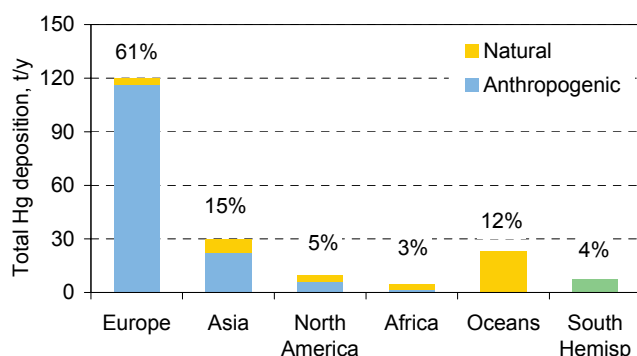
Mercury depositions caused by transboundary transport have decreased in all European countries (Figure 27). The decrease ranges mainly between 1.5 and 3 times. The highest decline took place in Ireland followed by Luxembourg and Iceland.



**Figure 27.** Decrease of mercury depositions from transboundary transport for 1990 – 2000.

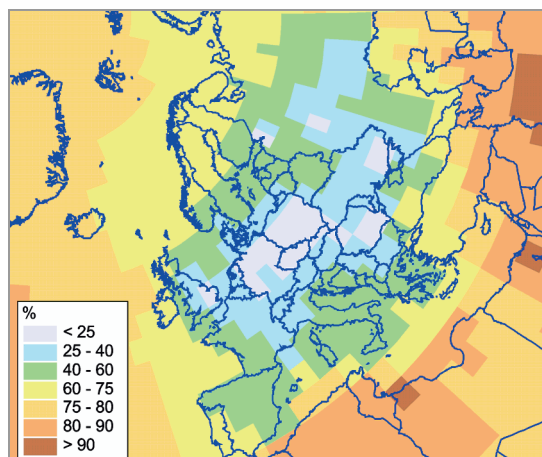
In contrast to lead and cadmium, mercury is a global pollutant, i.e. it can be transported by atmospheric flows all around the globe. That is why mercury emission sources located in other continents have a significant impact on pollution of Europe. Apart from that, natural emission sources and re-emission contribute significantly to mercury penetration to the atmosphere.

Evaluation of mercury intercontinental transport was made for 1996. Main regions - contributors of intercontinental mercury depositions in Europe are depicted in Figure 28. About 60% of deposited mercury to Europe came from its own sources and 40% – from sources located outside Europe.



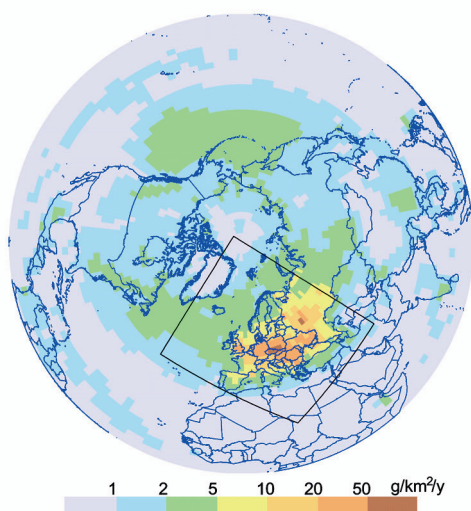
**Figure 28.** Contributions of global sources to mercury depositions in Europe in 1996. The last column of the chart – contribution of mercury transported from the Southern Hemisphere.

The contribution of non-European sources to mercury deposition fluxes in Europe is spatially non-uniform (Fig 29). Obviously, in the central part of Europe the contribution of external sources is the least. Over most part of Europe this contribution varied from 25 to 60% in 1996. On the periphery of the continent – in Scandinavia, west of the Iberian Peninsula, the contribution exceeded 60%, to the Caucasus – was more than 75%.



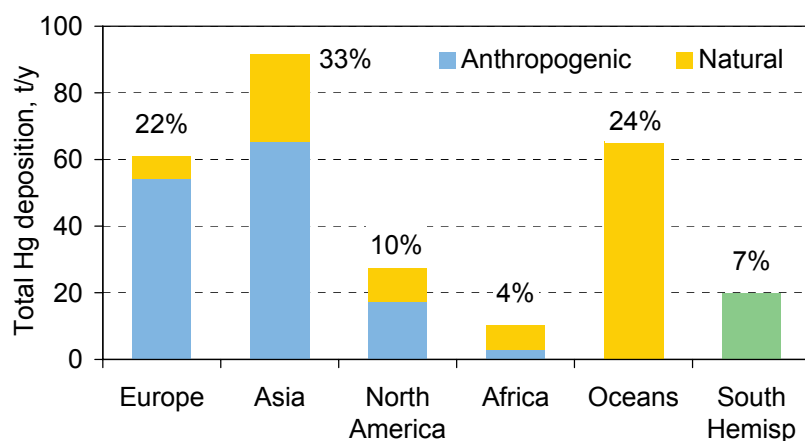
**Figure 29.** Relative contribution of non-European sources to mercury deposition in Europe in 1996.

Europe, in turn, is a source of global mercury pollution. Around 60% of mercury emitted in Europe was transported outside the region in 1996. Deposition fluxes of mercury from European sources exceed  $2 \text{ g/km}^2/\text{y}$  in such remote regions as South-eastern Asia, the North Pacific and the west of North America (Figure 30). Considerable levels of mercury deposition over the Northern Hemisphere were caused by the long - about a year - atmospheric lifetime of mercury.



**Figure 30.** Depositions of mercury from European sources in 1996. The black line is the border of the EMEP region in 1996.

The ability of mercury to travel over thousands of kilometres, results in elevated deposition levels in remote and vulnerable regions. One of such a region is the Arctic. More than 20% of depositions onto this region came from sources located in Europe in 1996 (Figure 31). Most of these sources were of anthropogenic origin. Other major anthropogenic sources of mercury atmospheric pollution in the Arctic were Asia and North America [Dutchak et al., 2003].

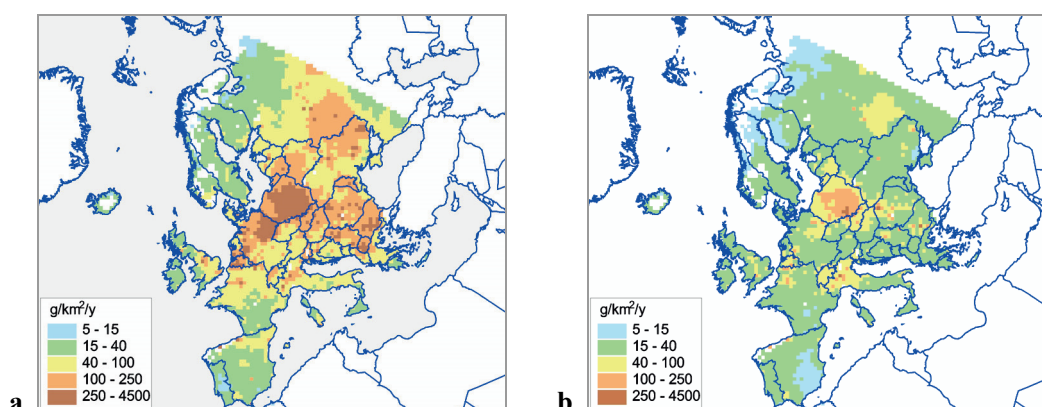


**Figure 31.** Contribution of different regions to the total annual deposition of mercury to the Arctic in 1996. The last column of the chart – contribution of mercury transported from the Southern Hemisphere.

#### 7.3.4. Special issues

##### *Ecosystem-dependent depositions*

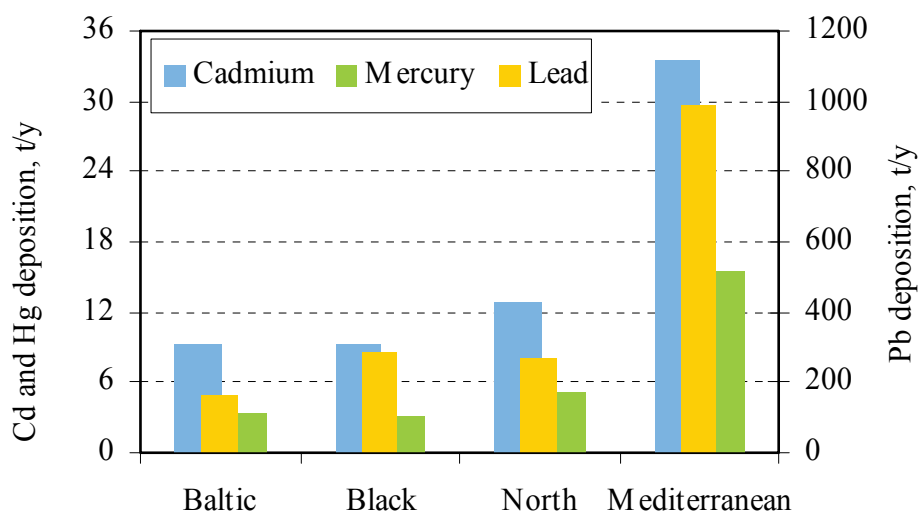
Research groups working with the effects of atmospheric pollution need information on ecosystem-dependent deposition fluxes. In order to provide them with this information, estimates of heavy metal depositions to various types of ecosystems were made. An example of cadmium decrease of depositions to arable lands in the period 1980-2000 is presented in Figure 32. More detailed information about ecosystem-dependent depositions of lead, cadmium and mercury one can find in the report [Ilyin et al., 2003] and in the Internet: <http://www.msceast.org>.



**Figure 32.** Deposition fluxes of cadmium to arable lands, 1980 (a) and 2000 (b).

*Pollution of marginal seas*

The seas surrounding Europe are receptors of airborne pollutants like heavy metals. Depositions of lead to the Baltic Sea amounted to about 150 t, of cadmium – about 10 t, of mercury – 3.5 t in 2000 (Figure 33). Depositions of these metals to other seas (the Black, the North, the Mediterranean) have a similar order of magnitude.



**Figure 33.** Lead, cadmium and mercury depositions to regional seas in 2000.

For the considered period atmospheric depositions of lead, cadmium and mercury declined due to the reduction of anthropogenic emissions. The rate of deposition decline was different for each metal and sea (Table 2). Since the rate of lead emission reduction was higher than that of cadmium, lead depositions to the regional seas cut down to a greater extent than cadmium depositions. The mercury depositions to the Black and the Baltic Seas in 1990 – 2000 almost halved. Mercury deposition reduction to the Mediterranean Sea was negligible.

**Table 2.** Decrease (times) of heavy metal depositions to regional seas for 1980–2000 (Pb, Cd) and 1990–2000 (Hg).

Sea	Lead	Cadmium	Mercury
Baltic	7.7	2.5	1.5
Black	4.3	2.2	1.3
North	10.9	2.0	1.7
Mediterranean	4.2	1.6	1.1

## 7.4. Conclusions

During the period of 1980-2000, levels of European pollution by lead and cadmium demonstrate a stable declining trend. The same could be indicated for mercury pollution levels during 1990 – 2000. Lead is characterized by the highest deposition decrease due to effective emission reduction. Atmospheric depositions of metals in countries of Europe depend on both national emissions and transboundary transport. The latter factor can contribute tens of percents to total heavy metal

depositions in countries. Therefore, in spite of significant reduction of pollution levels of heavy metals, transboundary transport continues to play an important role in atmospheric pollution in Europe. In case of mercury pollution significant impact is made by intercontinental transport to Europe.

## 7.5 References

- Axenfeld, F., Münch, J., Pacyna, J.M., Duiser, J.A. and Veldt, C., 1989. Emissionsdatenbasis für die Spurenelement As, Cd, Hg, Pb, Zn und für Spezielle Organische Verbindungen  $\gamma$ -HCH (Lindan), HCB, PCB und PAK. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit. Luftreinhaltung. Forschungsbericht 104 02 588. Dornier, Juli 1989.
- Berdowski, J.J.M., Pacyna, J.M. and Veldt, C., 1994. Chapter 3: Emissions: In: van den Hout, K.D. (ed.), 1994: The Impact of Atmospheric Deposition of Non-Acidifying Pollutants on the Quality of European Forest Soils and the North Sea. Main report of the ESQUAD project. Air and Energy Directorate of the Dutch Ministry of Housing, Spatial Planning and the Environment.
- Berdowski, J.J.M., Baas, J., Bloos, J.P.J., Visschedijk, A.J.H., Zandveld, P.Y.J., 1997. The European Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990. Forschungsbericht 104 02 672 / 03. Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit. TNO Institute of Environmental Sciences, Energy Research and Process Innovation.
- CACAR, 2003: Canadian Contaminants Assessment Report II, Sources, Occurrence, Trends and Pathways in the physical environment, Northern Contaminants program, Minister of Indian Affairs and Northern Development, Minister of Public Works and Government Services Canada, p.p. 332.
- Dutchak S. Fedyunin M., Gusev A., Ilyin I., Malanichev A., Mantseva E., Resnyansky Yu., Shatalov V., Strukov B., Travnikov O., Varygina M., Vulykh N. and Zelenko A. [2003]. Assessment of long-range transport of Hg, PCBs and  $\gamma$ -HCH to the Russian North. EMEP/MSC-E Technical Report for AMAP, 260 pgs.
- Ilyin I., Ryaboshapko A., Afinigenova O., Berg T., Hjellbrekke A.G., Lee D.S. [2002]. Lead, cadmium and mercury transboundary pollution in 2000. MSC-E/CCC Technical Report 5/2002
- Ilyin I., Travnikov O., Ass W. and Ugerud H. Th. [2003]. Heavy metals: transboundary pollution of the environment. EMEP Status Report 2/2003. MSC-E, June, 2003. 40 pgs.
- Nriagu, J.O., Pacyna, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* 333 (6169): 134-139.
- Olendrzynski K., Anderberg S., Bartnicki J., Pacyna J., and Stigliani W., 1996. Atmospheric emissions and depositions of cadmium, lead, and zink in Europe during the period 1955-1987. *Environ. Rev.*, 4, pp. 300-320.

- Pacyna, J.M., 1983. Trace element emission from anthropogenic sources in Europe. Norwegian Institute for Air Research, NILU Technical Report No. 10/82. Lillestrøm, Norway.
- Pacyna, J. M. and E. G. Pacyna, 2000. Atmospheric emissions of anthropogenic lead in Europe: improvements, updates, historical data and projections. GKSS 2000/31 Geesthacht GmbH, Geesthacht, Germany. ISSN 0344-9629.
- Pacyna, E.G., Pacyna, J.M., 2001. An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide. *Environmental Reviews* 9: 269-298.
- Pacyna, E.G., Pacyna, J.M., 2002. Global emission of mercury from anthropogenic sources in 1995. *Water, Air and Soil Pollution* 137: 149-165.
- Pacyna, E.G., Pacyna, J.M., Pirrone, N., 2001. European emissions of atmospheric mercury from anthropogenic sources in 1995. *Atmospheric Environment* 35: 2987-2996.
- Pacyna JM, Breivik K., Münch J., Fudala J. 2003. European atmospheric emissions of selected persistent organic pollutants, 1970-1995. *Atmospheric Environment* 37: S119-S131.
- Pacyna, J.M., Pacyna, E.G., Steenhuisen, F., Wilson, S., 2003. Mapping 1995 global anthropogenic emissions of mercury. *Atmospheric Environment* 37: S109-S117.
- Vestreng, V., 2003. Review and Revision. Emission data reported to CLRTAP. MSC-W Status Report 2003. EMEP/MSC-W Note 1/2003.
- von Storch, H., Costa-Cabral, M., Hagner, C., Feser, F., Pacyna, J.M., Pacyna, E.G., Kolb, S., 2003. Four decades of gasoline lead emissions and control policies in Europe: a retrospective assessment. *The Science of the Total Environment* 311: 151-176.