

Chapter 8

Persistent Organic Pollutants

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8.1 Introduction

The POPs Protocol

The Executive Body adopted the Protocol on Persistent Organic Pollutants (POPs) on 24 June 1998 in Aarhus (Denmark). As of 13 September 2004, it has been ratified by 21 parties and it entered into force on 23 October 2003. It focuses on a list of 16 substances that have been singled out according to agreed risk criteria (*potential for long range transport, persistency, bioaccumulation, toxicity*). The current list of substances comprises eleven pesticides, two industrial chemicals and three by-products/contaminants. The ultimate objective of the Protocol is to eliminate any discharges, emissions and losses of POPs. The Protocol bans the production and use of some products outright (*aldrin, chlordane, chlordecone, dieldrin, endrin, hexabromobiphenyl, mirex and toxaphene*). Others are scheduled for elimination at a later stage (*DDT, heptachlor, hexachlorobenzene, PCBs*). Finally, the Protocol severely restricts the use of DDT, HCH (*including lindane*) and PCBs. The Protocol includes provisions for dealing with the wastes of products that will be banned. It also obliges Parties to reduce their emissions of dioxins, furans, PAHs and HCB below their levels in 1990 (or an alternative year between 1985 and 1995). For the incineration of municipal, hazardous and medical waste, it lays down specific limit values. A Task Force on POPs has additionally been established, that will prepare technical reviews on dossiers of new substances by Parties for potential inclusion into the Protocol.

The rapid growth in chemical and agrochemical industries during the last century have resulted in the environmental releases of a large number of new chemical compounds into the environment. According to the OECD, the daily use of chemicals includes about 70,000 mainly organic synthetic chemicals, and the number increases continuously (Schwarzenbach et al. 1993). Over the last decades, there has been an increasing focus on a subset of harmful organic chemicals, mostly of anthropogenic origin, that are commonly classified as Persistent Organic Pollutants (POPs). The group of intentionally produced chemicals discussed here include the polychlorinated biphenyls (PCBs) that were introduced in 1929, as well as γ -hexachlorocyclohexane (γ -HCH) that has been produced as an insecticide since the 1940s. In addition, a number of potentially harmful organic chemicals are released as accidental and unwanted by-products from various industrial activities and combustion processes. This group includes the polychlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs) as well as the polyaromatic hydrocarbons (PAHs).

POP substances often have 3 characteristics in common (i) one or more cyclical ring structures of either aromatic or aliphatic nature, (ii) a lack of polar functional groups, and (iii) a variable amount of halogen substitutions, usually chlorine. Typically, POPs are long-lived in the environment (*persistent*), lipophilic (*bio-accumulative*), occur to a significant extent in both the gas phase and condensed states (*semi-volatile and thus prone to long-range transport*) as well as toxic (see e.g. Vallack et al. 1998; Jones and de Voogt, 1999). For most other pollutants, concentrations tend to decrease from the point of release due to dispersion, degradation and dilution. However, circumstances have been described where concentrations of POPs have been higher in remote regions than in source regions (Wania, 1999). Examples of this are elevated concentrations of POPs in Arctic and high mountain regions (e.g. Wania and Mackay, 1996). In this chapter, only a few POPs are addressed as representatives of this diverse group of pollutants.

PAHs: PAHs are a class of high molecular organic compounds with three or more fused benzene rings, although bicyclic compounds (for example, naphthalene and biphenyl) sometimes are included to this class. The aromatic structure of PAHs can include other types of rings, such as five-membered carbon or heteroaromatic rings. Many PAHs meet several of the criteria that have been suggested in order to classify them as POPs. However, their carcinogenicity is of a particular interest. The International Agency for Research on Cancer (IARC) has previously classified 14 out of 50 PAHs assessed as potentially hazardous for man.

PCDD/Fs refer to chlorinated tricyclic hydrocarbons. PCDD/Fs include 210 possible congeners, combined in 14 homologue groups with different chlorination level. Physical-chemical properties of these congeners are different, leading to differences in their environmental behavior. The toxic properties of PCDD/F are fairly well-known and characterised. The most toxic forms of PCDD/Fs are the 2,3,7,8-PCDD/Fs.

PCBs are referred to a class of organochlorine aromatic compounds, which have been used in many countries for a long period of time. There are 209 possible PCB congeners with different physical-chemical properties and toxicity depending on the number and position of chlorine atoms on the biphenyl molecule. According to International Agency of Research on Cancer (IARC) PCBs belong to group of probable carcinogens for man. PCBs can affect the human reproductive system and exhibit embryotoxic effect. A number of PCB congeners with coplanar configuration possess toxicological properties similar to that of the PCDD/Fs.

γ -HCH is one of eight possible isomers of 1,2,3,4,5,6-hexachlorocyclohexane (HCH), thus belonging to the group of organochlorine compounds. γ -HCH is the HCH isomer that possesses the highest insecticidal activity. γ -HCH exhibits mutagenic, embryotropic, sensibilizing and irritating activity and affects reproduction processes.

8.2. Emissions of POPs

If we are to understand and control the wide-spread environmental pollution of POPs, it is important to obtain knowledge of the sources of POPs. The 1998 Aarhus Protocol on Persistent Organic Pollutants now has 36 signatories and 18 ratifications (as of Jan. 21, 2004), and the protocol entered into force by the end of 2003. Reliable data on emissions of Persistent Organic Pollutants (POPs) are thus increasingly important for decision makers aiming at further reduction of the environmental loading of such substances into the environment. Such data are also needed for the review of the Aarhus Protocols on POPs, which should take place no later than one year after it entered into force (Vestreng, 2003).

Emission information is also essential for modelling activities within EMEP, aiming at interpreting historical, current and future contamination levels in remote areas. All emission data for POPs presented herein (8.2.1-8.2.4) are compiled on the basis of available official emission data and expert estimates. A general discussion of the current status of emission inventories for POPs is included in section 8.2.5.

8.2.1 Emissions of PAHs

The atmospheric emissions of PAHs are mainly due to incomplete combustion of fossil fuels. The amount and composition of PAHs emitted are to a large extent determined by the composition of the raw materials, the combustion temperature, oxygen availability and potential abatement technologies.

Trends (1980-2000)

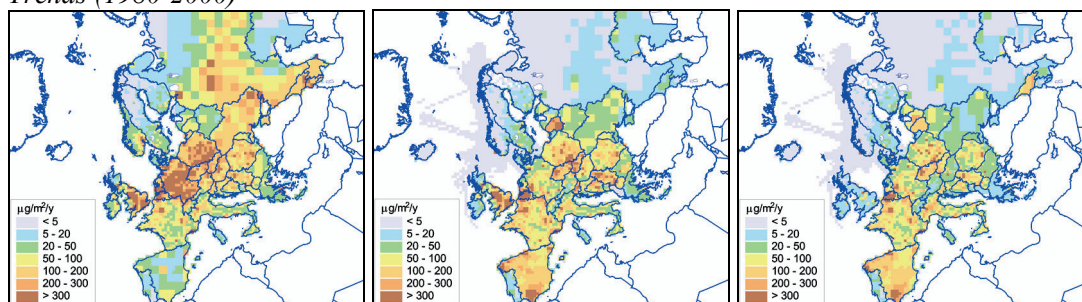


Figure 8.1 Atmospheric emissions of B[a]P in Europe in 1980 (left), 1990 (middle) and 2000 (right), $\mu\text{g}/\text{m}^2/\text{y}$.

Benzo[a]Pyrene (B[a]P) is among the most studied PAHs. In 1980, various production processes was a key source category of B[a]P to the atmosphere. This source category has seen significant reductions in Europe over the last two decades. By the mid-1990s, non-industrial combustion plants was the most important source category in controlling atmospheric emissions of B[a]P in most European countries.

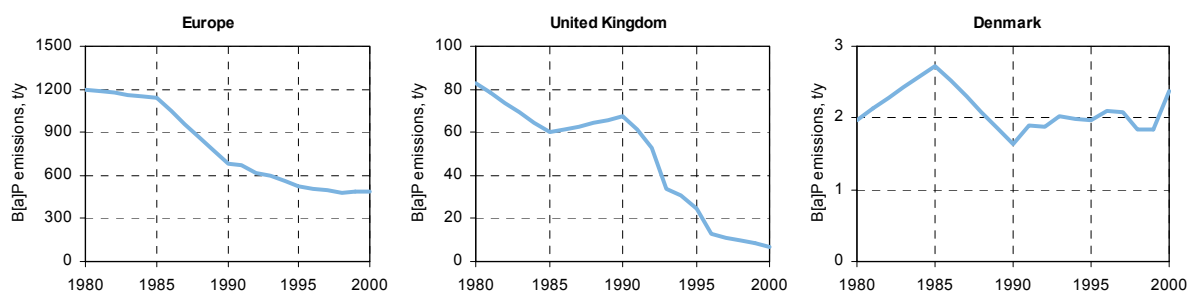


Figure 8.2 Temporal trend in emissions of B[a]P in Europe (left), United Kingdom (middle) and Denmark (right) from 1980 to 2000, t/y.

Total B[a]P emissions have been reduced almost three times during the period from 1980 to 2000. However, trends of B[a]P emissions in particular countries can be different (Figure 8.2).

For example, emissions in some countries of Eastern Europe did not change much in the early period due to insignificant developments in technology and environmental legislation until the early 1990s (Pacyna et al 2003).

8.2.2 Emissions of PCDD/Fs

PCDD/Fs (polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)) are unintentional by-products of various combustion processes where chlorine is present. For these compounds there are several sources, and many are not well characterized.

Trends (1980-2000)

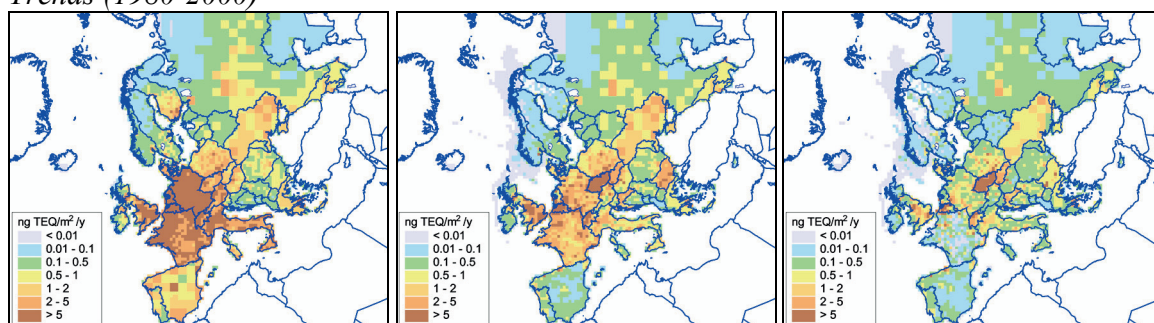


Figure 8.3 Atmospheric emissions of PCDD/Fs in European countries in 1980 (left), 1990 (middle) and 2000 (right), ng TEQ/m²/y.

Measures have been undertaken over the last decades to reduce the emissions from important source categories due to the major concern about the toxicity of PCDD/Fs. The rate of decrease of PCDD/F emissions in particular countries are different for different time periods (Figure 8.3). However, total PCDD/F emissions have been reduced almost five times during the period from 1980 to 2000 (Figure 8.4).

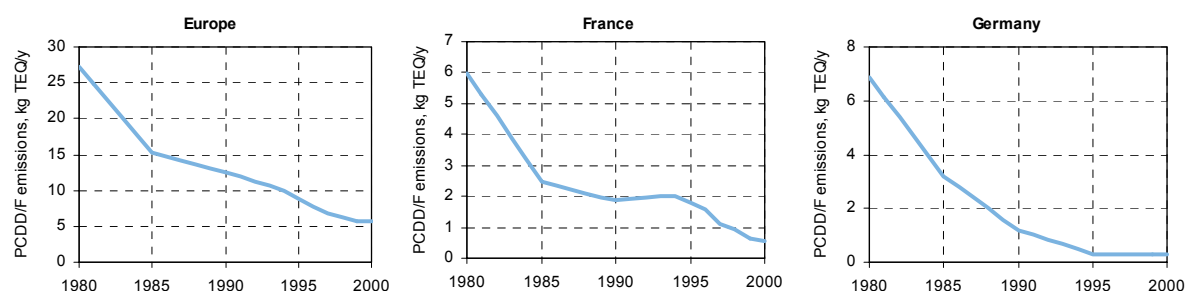


Figure 8.4 Temporal trend in emissions of PCDD/Fs in Europe (left), France (middle) and Germany (right) from 1980 to 2000, kg TEQ/y.

According to Pacyna et al (2003), the three most important major source categories in Europe during the mid-1990s were: (i) non-industrial combustion plants, (ii) production processes and (iii) waste treatment and disposal. While industrial production most likely was the principal source of PCDD/Fs

in the 1970s, the relative importance of waste incineration is increasing. The temporal development reflects the more efficient reduction of the emissions from larger “hot spots” than from smaller plants.

8.2.3 Emissions of PCBs

Primary anthropogenic atmospheric emissions of PCBs may be due to (i) historical intentional production, consecutive use and disposal of products or materials containing PCBs, or (ii) incidental formation of PCBs in various combustion processes. Dated sediment and peat core studies indicate that the historical contamination trend has mirrored the production and use of PCBs.

The PCBs are commonly considered as key representatives of the “industrial” POPs. Between 1 and 2 million tonnes of PCBs were produced worldwide between 1930 and 1993. It has been suggested that almost 97% were used in the Northern Hemisphere (Breivik et al 2002a). In general, published emission estimates for PCBs are difficult to compare as the methodological and empirical basis are different (Breivik et al 2002b; Breivik et al 2004). Still, the results of both emission inventories and monitoring data in source regions indicate a decrease in atmospheric emissions over the last few decades, following measures in various countries to eliminate the production and reduce the use of PCBs during this time period (Figure 8.5).

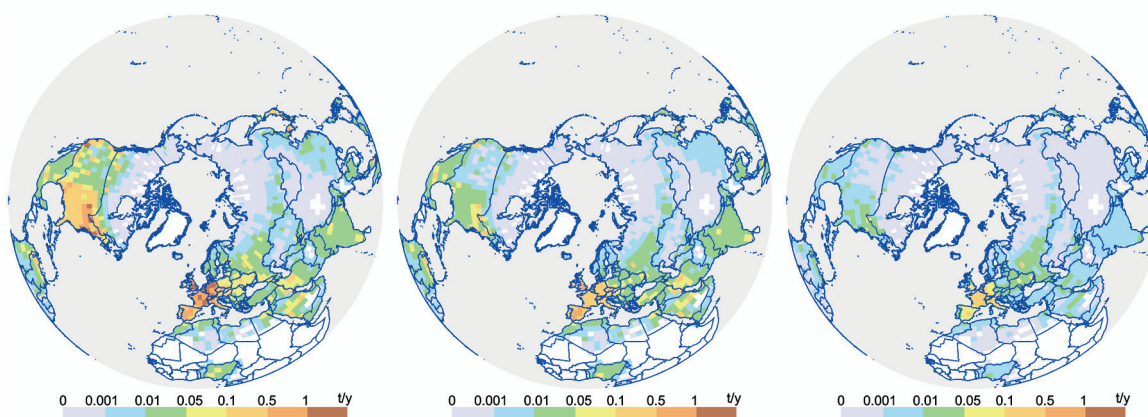


Figure 8.5 Atmospheric emissions of PCB-153 in the Northern Hemisphere in 1980 (left), 1990 (middle) and 2000 (right), t/y.

8.2.4 Emissions of γ -HCH

Atmospheric emissions of γ -HCH are mainly a result of the use of the insecticides lindane (>99% γ -HCH) and technical HCH (8-15% γ -HCH).

The global usage of technical HCH and lindane in 1980 and 1990, was presented by Li et al (1996). The total global usage of γ -HCH was found to be around 11 900 tonnes in 1980 and 8400 tonnes in 1990. These data indicate that technical HCH and lindane have been about equally important as a

source of γ -HCH to the environment on a global scale. In comparison, data for Europe indicate that usage of technical HCH was the major source of γ -HCH to the environment until the late 1970s, whereas lindane became the dominating source of γ -HCH in the years thereafter (Breivik et al 1999). It has recently been reported that usage of technical HCH apparently has ceased globally (Li et al 2003). However, usage of lindane seems to continue in certain countries, such as China and North America (e.g. Li et al 2004; AMAP 2004).

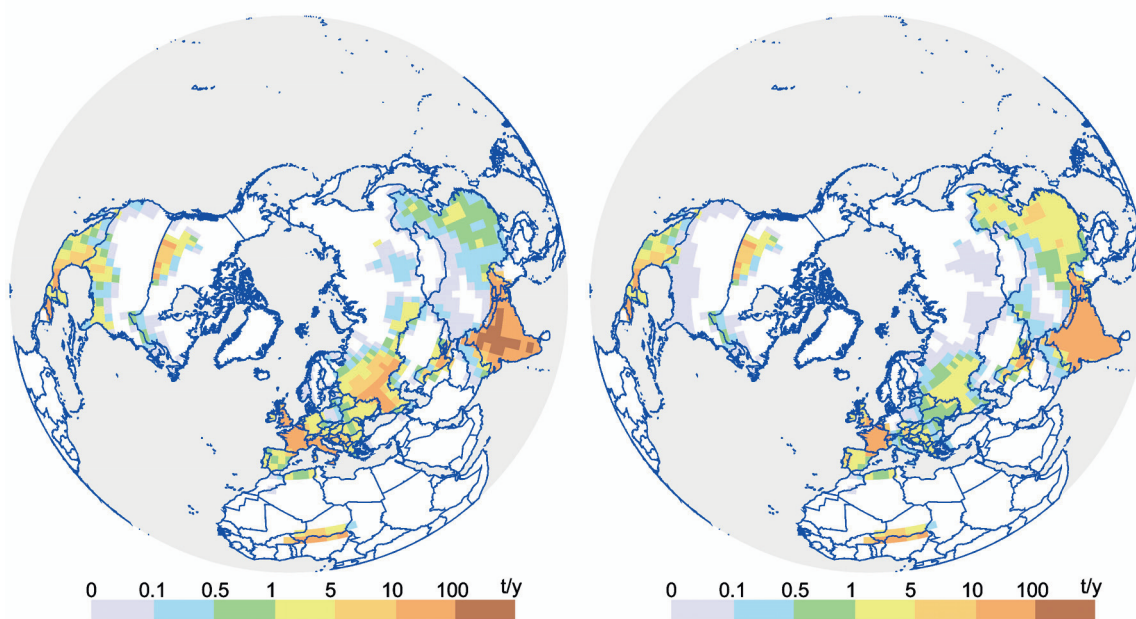


Figure 8.6 Atmospheric emissions of γ -HCH in the Northern Hemisphere in 1990 (left) and 1996 (right), t/y.

8.2.5 Discussion

Although significant improvements in our understanding of POP emissions have been made over the last decade, it probably remains the least understood part of the overall distribution and fate of these chemicals in the environment (Wania and Mackay, 1996; Vallack et al 1998; Jones and de Voogt, 1999; Breivik et al. 2004). There is a general need for further measurements and characterisation of the emissions of POPs at source. The methodological and empirical basis of emission estimates remains the weakest element in terms of POP control. Table 1 presents official submissions of national POP emission totals to EMEP during the period from 1996 to 2001 (Vestreng, 2003). These data are reported to MSC-W two years after the reference year given in this table. It is evident from Table 1 that there is still a substantial data gaps in the officially reported data for POPs.

The spatial and temporal incompleteness of current emissions (Table 8.1) explains why it is difficult to predict reliable source-receptor relationships for POPs over the EMEP model domain, based on officially submitted emission data alone. Therefore, non-official expert estimates are often utilised as model input in the absence of official emission data. Some of these studies have focused on emissions across the European region (e.g. Berdowski et al. 1997, Breivik et al. 1999; Pacyna et al. 2003a; Quaß et al. 2004) whereas others have a global coverage (e.g. Li et al 2000,2003; Breivik et al. 2002a,b; Fiedler 2003) to facilitate an analysis of the global dimensions to the POP contamination problem. A

more detailed account of the current status of regional and global scale emission inventories for POPs may be found in Breivik et al (2004).

Table 8.1 Official submissions of POP 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
Aldrin	5	5	5	5	2	2
Chlordan	6	5	5	5	2	2
Chlordecone	5	5	5	5	2	2
Dieldrin	5	5	5	5	2	2
Endrin	5	5	5	5	2	2
Heptachlor	6	5	5	5	2	2
Hexabromobiphenyl	4	4	4	4	2	2
Mirex	5	5	5	5	2	2
Toxaphene	6	5	5	5	2	2
HCHs	8	8	7	4	4	4
DDT	5	5	5	5	3	4
PCBs	10	10	10	10	11	9
Dioxins and furans	13	21	22	20	18	17
PAHs	22	24	24	23	24	23
HCB	15	15	14	14	11	11
Other (PCP, SCCP)	10	10	9	9	8	8

For POPs, it is desirable to have information on historical emissions within a timeframe that reflects the potential lifetime of these compounds in the environment (which could be on the order of decades or even more). This is because environmental levels at present do not necessarily reflect current emissions. Over the last few years, several studies have therefore addressed temporal trends in emissions. In addition to the data that are reported by countries to EMEP, more detailed investigations have additionally been carried out for various hexachlorocyclohexanes (Breivik et al 1999; Li et al 2000; 2003), polychlorinated biphenyls (Breivik et al 2002a,b), dioxins and furans (e.g. Quaß et al 2004) and other POPs (Pacyna et al 2003). In general, all these studies suggest decreasing trends in emissions over the last few decades for the specific POPs mentioned above. The reasons for this decrease in emissions are dependent on the pollutant in question. For industrial chemicals (e.g. PCBs) and pesticides (e.g. lindane), reduction is mainly due to the reduced production and restricted use of these chemicals. The decrease in emissions of unwanted byproducts of combustion (e.g. PCDD/Fs) is mainly caused by implementation of abatement equipment. However, the environmental response to changes in emissions of POPs is more difficult to assess as it depends on the proximity to source regions, the physical-chemical properties and environmental lifetime of the compound in question as well as the environmental media studied. This is discussed in the following paragraphs.

8.3. Pollution by POPs

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. POPs were included in EMEP's monitoring program in 1999. However, earlier data has 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/cce). A number of countries have been reporting POPs within the EMEP area in connection with different national and international programmes such as HELCOM, AMAP and OSPAR. The number of stations have been increasing, and in 2001 it was 13 measurement sites altogether. Among them 6 sites measure POPs in both in air and in precipitation (Figure 8.7).

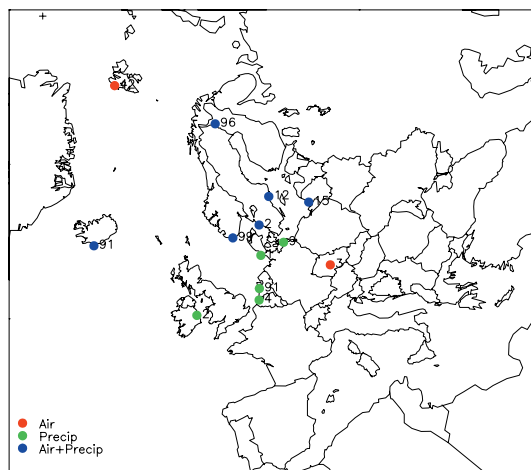


Figure 8.7 Measurement network of POPs, 2001.

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 transport (depositions and concentrations). For the assessment of contamination of the European region by POPs EMEP multicompartiment model is used. It includes main environmental processes (atmospheric and marine transport, dry and wet deposition, gaseous exchange between the atmosphere and the underlying surface such as soil, seawater and vegetation, degradation in the environmental media). In hemispheric version the influence of sea ice on POP fate in the environment is taken into account. The following chapter provides an overview of POP (PAHs, PCBs, HCHs, PCDD/F) pollution levels in Europe in the period from 1980 to 2000. The results of the assessment of European pollution by POPs were used by Task Force on Health in evaluation risks for humans (WHO, 2003).

8.3.1. Pollution by polyaromatic hydrocarbons

Representatives of this class of hydrocarbons can be found almost in all natural objects – in air, soil and water entering there from natural and anthropogenic sources. Measurement results demonstrate a widespread occurrence of PAHs in the atmosphere of the whole globe including data on background and remote territories. Monitoring data evidence that PAH content in the environment essentially increases in regions of active economic activity. The reason for PAH accumulation in the biosphere is their stability, which along with their emissions defines their abundance in the environment.

Trends of PAH content in main environmental media and spatial distributions of these pollutants in the EMEP region during 1980-2000 are exemplified by B[b]F, whereas the evaluation of the role of transboundary transport in the formation of pollution levels in European countries in 2000 is exemplified by B[a]P.

Emission and concentration trends. In the period from 1980 to 2000 B[b]F emissions were reduced by half. The same level of reduction took place for concentrations in air and seawater. The drop of B[b]F soil concentrations amounted only to 30% (Figure 8.8). Similar behavior is also characteristic of

B[a]P. For PAHs soil is the most inertial media accumulating the bulk of total content of these pollutants in the environment (over 90%).

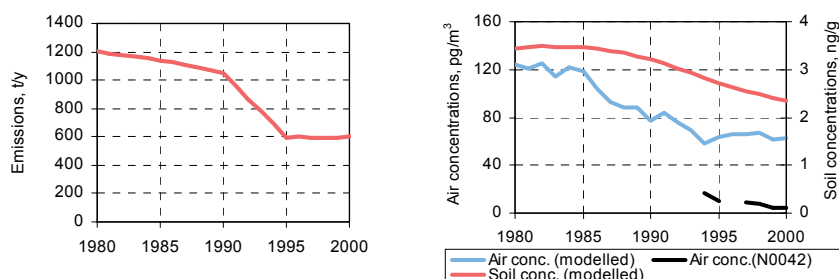


Figure 8.8 Trends of B[b]F emissions (left) and concentrations in air (modelled and measured at NO0042) and soil (right) in Europe for 1980 – 2000

Spatial distribution of pollution. Spatial pattern of the atmospheric pollution in the EMEP region in 1980 compared with that in 2000 is shown in Figure 8.9. Atmospheric concentration levels are essentially cut down in western and northern parts of Europe.

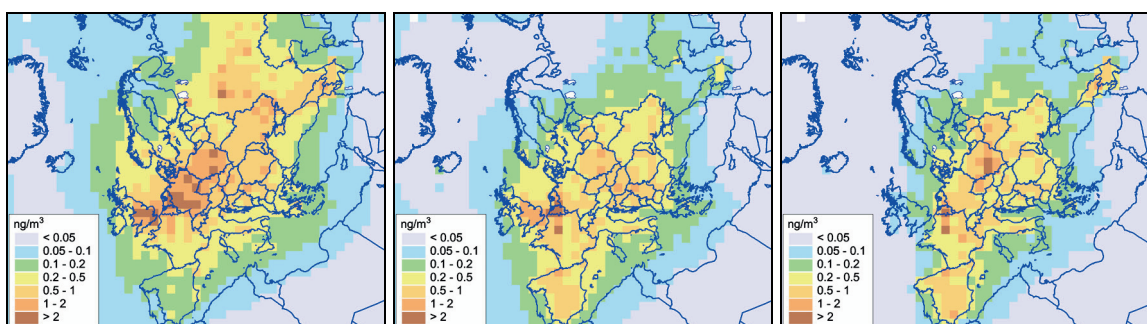


Figure 8.9 Spatial distribution of B[b]F concentrations in air for 1980 (left), 1990 (middle), and 2000 (right), ng/m^3 .

The reduction of air concentrations in each European country in the period from 1980 to 2000 is demonstrated in Figure 8.10. The largest decrease (from 4 to 8 times) takes place in the United Kingdom, Norway, the Netherlands, Ireland, Iceland, Germany.

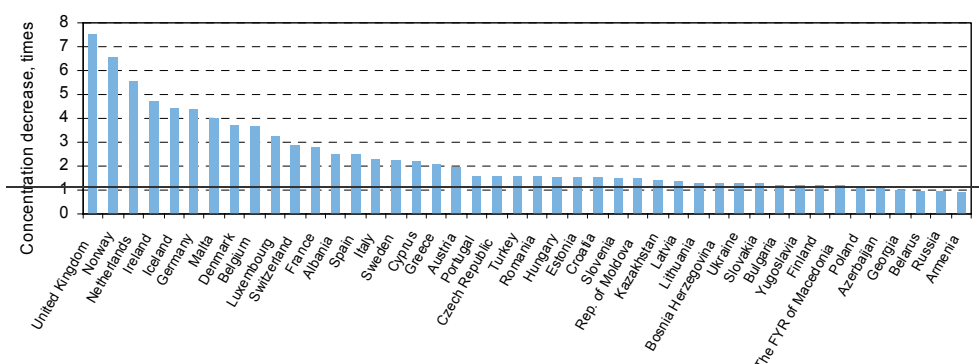


Figure 8.10 Decrease of B[b]F air concentrations for 1980-2000, times.

Trends of the decrease of B[b]F pollution in two European countries are shown in Fig 8.11.

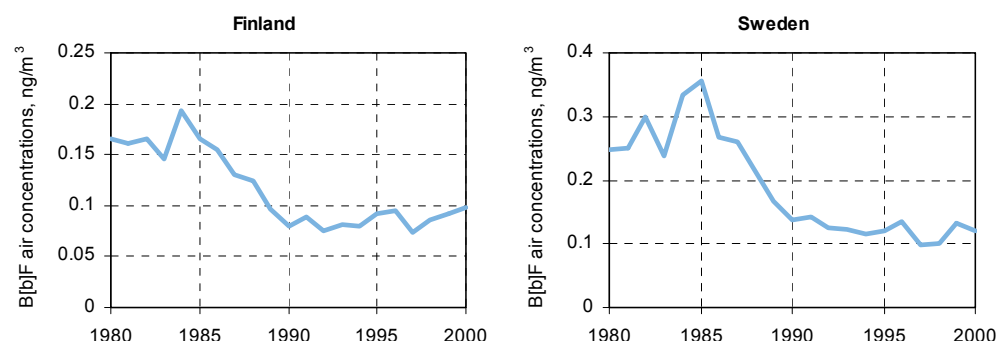


Figure 8.11. Trends of the air concentrations decrease of B[b]F in Finland (left) and Sweden (right) for 1980-2000, ng/m³.

Transboundary transport. In spite of strong reduction of contamination in Europe, the role of the transboundary pollution remains essential. It is demonstrated on the example of B[a]P. The contributions of external sources to air concentrations in various European countries are shown in Figure 8.12.

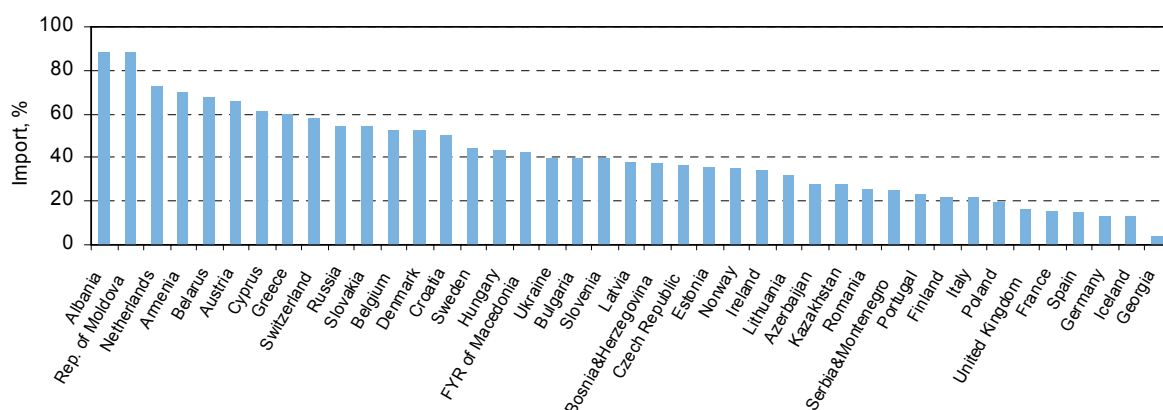


Figure 8.12 Contribution of the transboundary transport of B[a]P to air concentration in European countries in 2000, %.

In most countries the transboundary contribution is within the range from 30 to 80%. At the same time transboundary contributions are not uniformly distributed over a country. This is exemplified here by France – the country with the total transboundary contribution about 20%. The transboundary contributions in particular places of the country vary from 10 to 60% and can even exceed 60% in areas near boundaries with neighboring countries (Figure 8.13). The contributions of emission sources of other countries to the total deposition of B[a]P to France is shown in Figure 8.14.

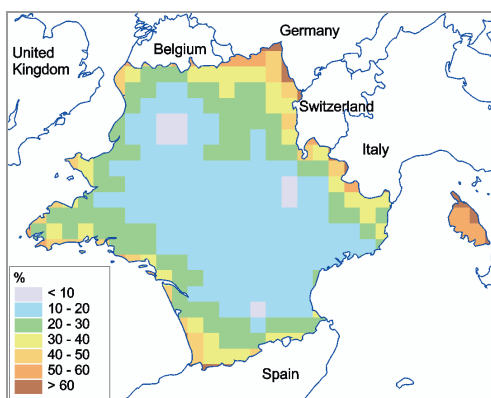


Figure 8.13 Contribution of transboundary depositions of B[a]P in France in 2000, %

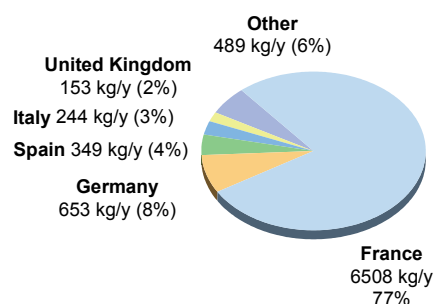


Figure 8.14 Contribution of European countries to B[a]P deposition in France in 2000, kg/y (%)

The assessment of the transboundary transport for other European countries can be found on the Internet, <http://www.msceast.org>.

8.3.2. Pollutions by polychlorinated dibenzo-p-dioxins and dibenzofurans

Never produced intentionally PCDD/Fs are formed as by-products of numerous industrial activities and all combustion processes. They are environmental ubiquitous and detectable in almost all compartments of the global ecosystem in trace amount. PCDD/Fs are characterized by their ability to be transported over long distance and by high bioaffinity.

Emission and concentration trends. For the period from 1980 to 2000 emissions of PCDD/Fs in the EMEP domain has been reduced slightly less than 5 times (Figure 8.15, left). As a result the concentrations of PCDD/Fs in the atmosphere decreased about 4 times. Relatively slow decrease of air concentrations in comparison with emission reduction can be explained by re-emission from soil to the atmosphere. At the same time soil concentrations in top soil layer (5 cm) decreased only by 20% (Figure 8.15, right). There are only modelled concentrations of atmospheric concentrations of PCDD/Fs at the moment.

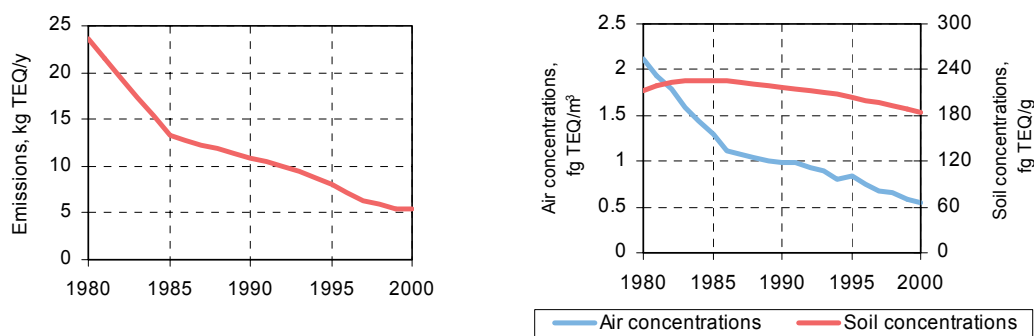


Figure 8.15 Trends of PCDD/Fs emissions (left) and concentrations in air and soil (right) for 1980-2000.

Low decrease of soil concentrations is conditioned by high persistence of PCDD/Fs in this media and by high soil accumulation capacity. Soil contains about 90% of total environmental content of PCDD/Fs.

Spatial distribution of pollution. The spatial pattern of the atmospheric pollution in the EMEP region in the period from 1980 to 2000 was also essentially changed (Figure 8.16). Reductions of air concentrations in European countries are different (Figure 8.17). The largest decrease (almost 6-9 times) is characteristic of the Netherlands, France, Germany, Finland, Sweden, the United Kingdom.

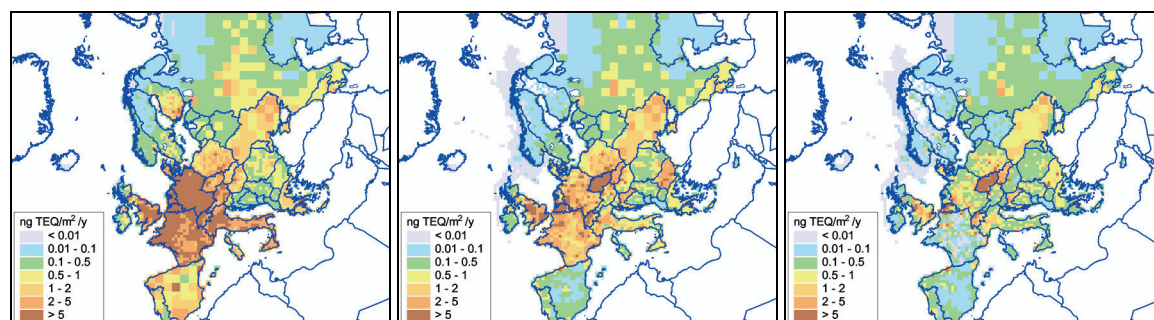


Figure 8.16 Spatial distribution of PCDD/Fs concentrations in air for 1980 (left), 1990 (middle), and 2000 (right), ng TEQ/m²/y.

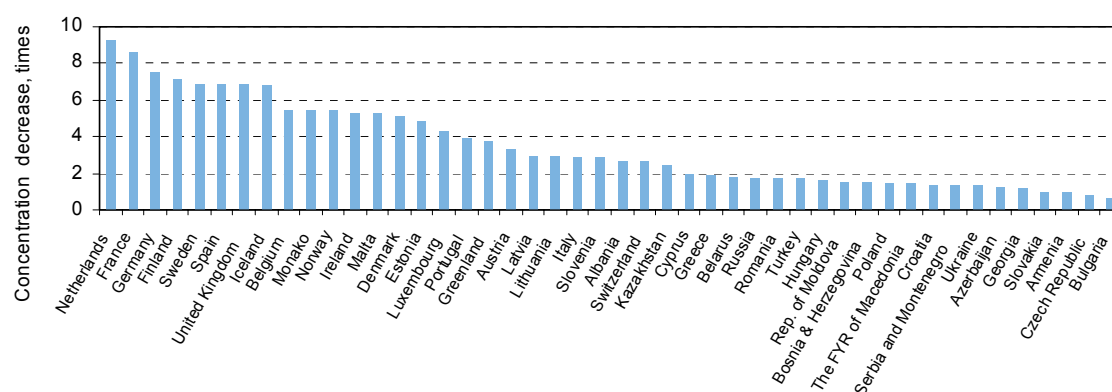


Figure 8.17 Decrease of PCDD/Fs air concentrations for 1980-2000, times.

Trends of the decrease of PCDD/F pollution in two European countries is shown in Fig 8.18.

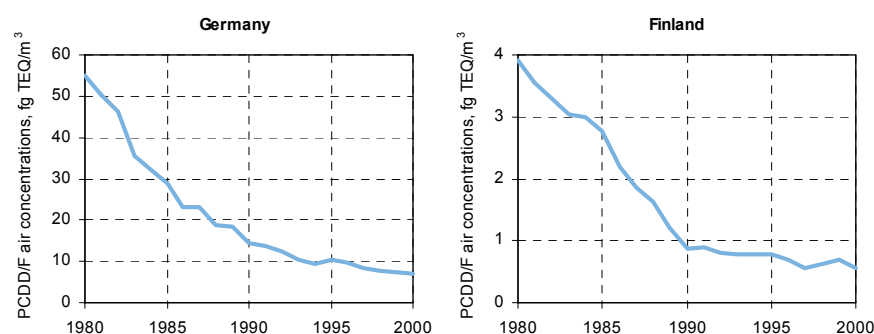


Figure 8.18. Trends of the air concentrations decrease of PCDD/F in Germany (left) and Finland (right) for 1980-2000, fg TEQ/m³.

Transboundary transport essentially affects environmental pollution by PCDD/Fs. This is exemplified below by trends of emissions and air concentrations in two European countries (Germany and Finland) (Figure 8.19). The influence of transboundary transport is particularly noticeable in the last decade of the considered period (from 1990 to 2000). It can be seen that the reduction rates of air concentrations are not determined by the rates of emission reduction. In Germany emissions decrease faster than in Europe as a whole. However, due to transboundary transport air concentrations in this country decline slower than emission reduction. In Finland emissions remain at one and the same level from 1990 to 2000 whereas the decrease of air concentrations also takes place. This effect can be explained by decrease of transboundary transport to the country.

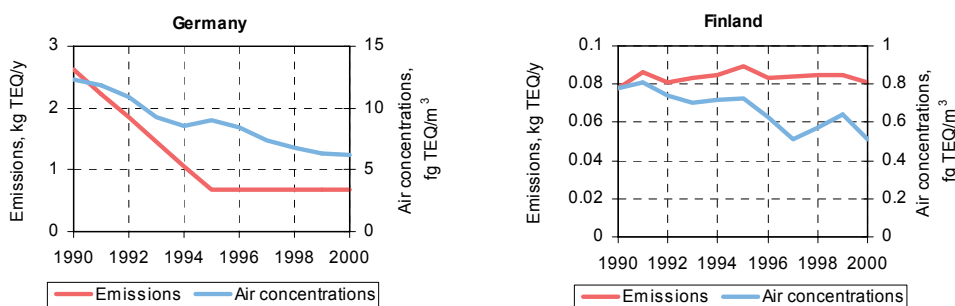


Figure 8.19 Trends of PCDD/Fs emissions and air concentrations in Germany (left) and Finland (right) for 1990-2000.

8.3.3. Pollution by polychlorinated biphenyls

PCBs are typical POPs since they are resistant to external effects. They have high thermal stability, essential photo-stability and low reactivity. Due to high lipophily PCBs readily accumulate in tissues of man, animals, birds and aqueous organisms. These compounds are readily sorbed on particle surface and soil. Numerous measurements demonstrate that PCBs are omnipresent in environmental compartments including the Arctic region. For brevity we demonstrate the assessment by the example of PCB-153.

Emission and concentration trends. Considerable emission reduction of PCB (almost 10 times) takes place over the whole Northern Hemisphere beginning from 1985 (Figure 8.20). Consequently, contamination of different environmental compartments by PCBs is also reduced. The reduction of the concentration levels in the atmosphere is about 6 times. The reduction of soil contamination strongly lags behind the reduction of atmospheric concentrations and amounts to 40% only. The comparison of trends for air and soil concentrations is presented in Figure 8.21.

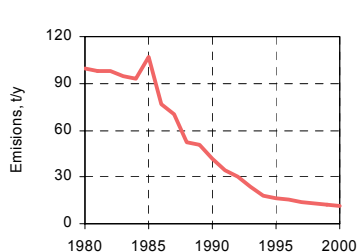


Figure 8.20. Trend of PCB-153 emissions in the Northern Hemisphere for 1980-2000, t/y.

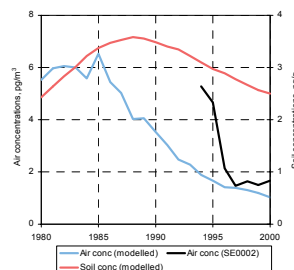


Figure 8.21. Trends of PCB-153 concentrations in air (modeled and measured at SE0002) and soil in the Northern Hemisphere for 1980-2000.

Thus, soil is the most inertial medium and PCB contamination in it can be kept during rather long time period (several decades) even at strong emission reduction. Re-emission from soil can support atmospheric pollution.

Spatial distribution of pollution in Europe. In Europe, PCB emissions have been reduced about 6 times during the period from 1980 to 2000 (Figure 8.22).

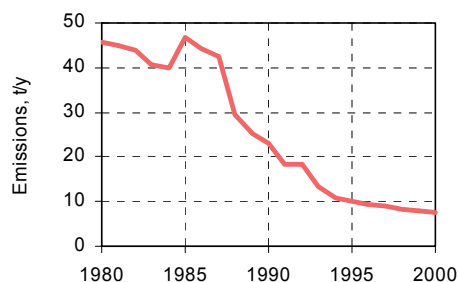


Figure 8.22 Trend of PCB-153 emissions in Europe for 1980 – 2000, t/y.

Spatial distribution of air concentrations in the Northern Hemisphere and in Europe in 1980 and in 2000 is shown in Figure 8.23.

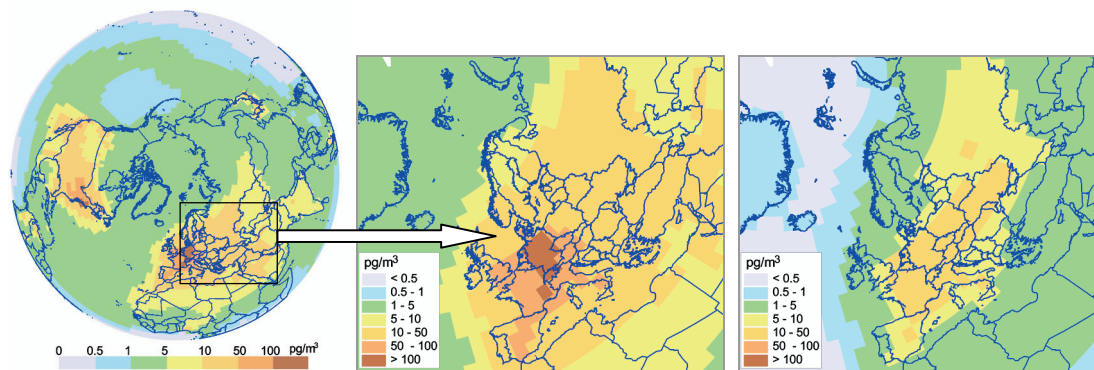


Figure 8.23 Spatial distribution of PCB-153 air concentrations in the Northern Hemisphere in 1980 (left) and in the EMEP domain in 1980 (middle) and in 2000 (right), pg/m^3 .

The largest reduction of air concentrations takes place in western and northern parts of Europe. In 2000, high values of atmospheric concentrations (more than 10 pg/m^3) took place in the central part of Europe (Figure 8.23, right). Lower concentration levels ($5 - 10 \text{ pg/m}^3$) are characteristic of the rest part of Europe except for its northern part where concentration levels range from 1 to 5 pg/m^3 .

Pollutant concentrations in soil are determined by a long-term accumulation process due to large accumulation capacity of soil and high persistence of PCB-153 in this medium. During 1980-2000 soil concentrations were kept approximately at one and the same level with slightly changed spatial pattern. In 2000, concentrations $0.1 - 0.2 \text{ ng/g}$ were observed both in regions with high air concentrations over central Europe and in the regions with lower air concentrations, in particular, in the UK (Figure 8.24). This could be explained by the fact, that in the period of 1970 – 1980 values of PCB emissions in the UK were rather significant and by high persistence of POPs in soil.

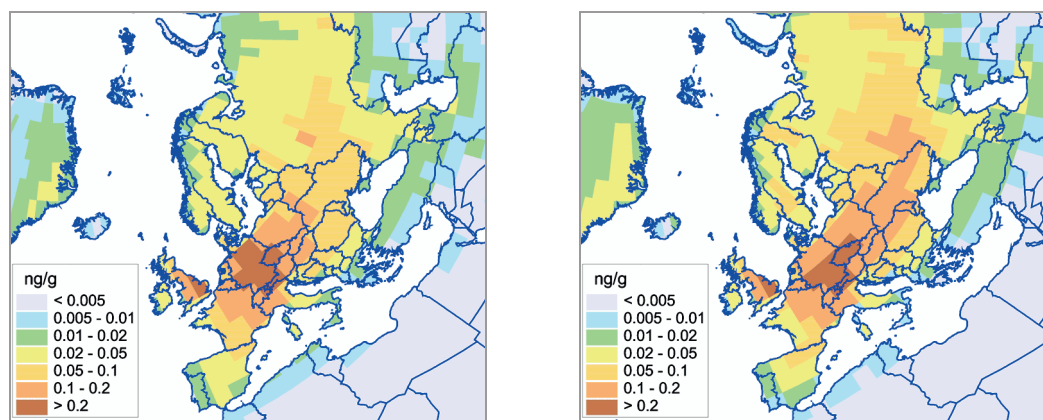


Figure 8.24 Spatial distribution of PCB-153 soil concentrations in 1980 (left) and in 2000 (right), ng/g.

Arctic pollution. The source-receptor relationships within the whole Northern Hemisphere and, in particular, the influence of European emission sources on the contamination of remote regions is of great importance. This is exemplified here by evaluation of pollution of the most vulnerable region of the Northern Hemisphere – the Arctic caused by the different sources (Figure 8.25). The contributions of emission sources from North-western and from South-eastern Europe to the Arctic contamination amount to about 40% and 16%, respectively. Due to high long-range transport potential of PCBs, the combined contributions of such remote sources as Africa and Asia is also considerable (about 8% together).

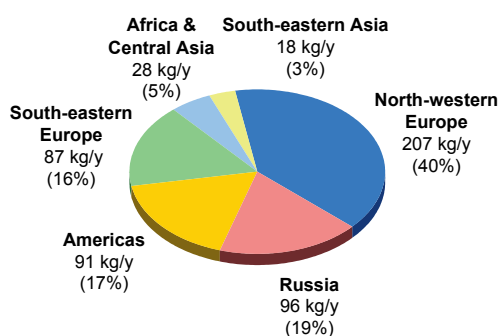


Figure 8.25 Contributions of PCB-153 source groups to the deposition to the Arctic region in 1996, kg/y (%).

8.3.4. Pollution by γ -Hexachlorocyclohexane

γ -HCH is one of the most volatile chemicals among the majority of organochlorine insecticides. Once HCH isomers enter the environment, they are distributed globally and can be found in air, surface water, soil, and living organisms (Walker et al., 1999). But HCHs are much less bioaccumulative than other organochlorines because of their relatively low lipophily and short half-life in biota. HCHs are the most abundant pesticides in the Arctic atmosphere and waters (Macdonald et al., 2000). The

detectable presence of these substances in such remote regions, where lindane and technical HCH have not been used, is an evidence of their long-range transport.

Emission and concentration trends. In the period 1990-1991 emissions over the Northern Hemisphere decreased by about 40%, whereas during the following five years their level cut down rather slowly (Figure 8.26, left). γ -HCH trend of concentrations in air follows the trend of emission. The content of this pollutant in soil changes very slowly due to a long half-life of γ -HCH in this medium (half-life in soil amounts to about 5 years). For γ -HCH main reservoir of accumulation is seawater. It contains more than 80% of this pollutant accumulated in the environment by the end of 1996.

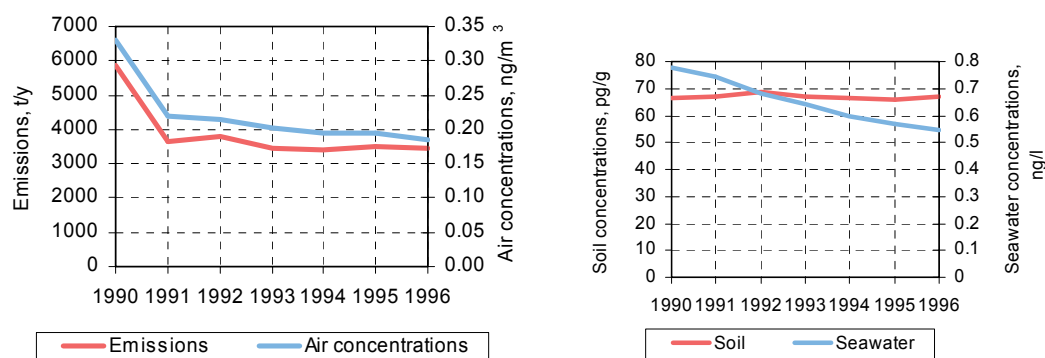


Figure 8.26 Trends of γ -HCH emissions and concentrations in air (left), soil and seawater (right) in the Northern Hemisphere for 1990-1996.

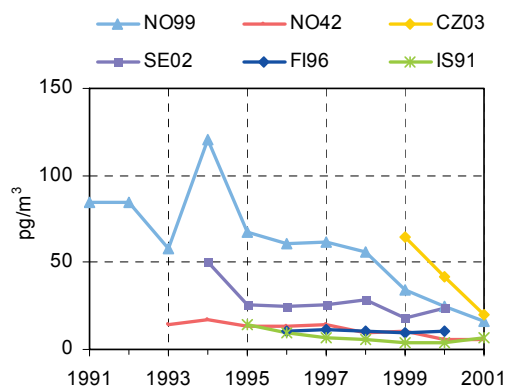


Figure 8.27. Trends in the atmosphere of γ -HCH measured at several EMEP stations for 1991-2001, pg/m³.

Spatial distribution of pollution in Europe. In Europe, emission reduction from 1990 to 1996 amounted 40% (Figure 8.28). The assessment of pollution levels in 1996 was done taking into account γ -HCH transport and accumulation in the environment within the period from 1990 to 1996.

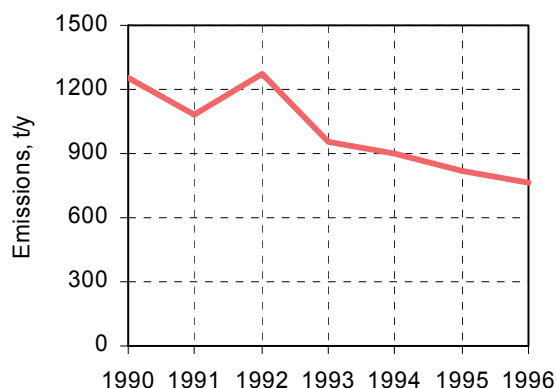


Figure 8.28 Trend of γ -HCH emissions in Europe for 1990 – 1996, t/y.

Air concentrations in the Northern Hemisphere and in Europe in 1990 are presented in Figure 8.29. (left and middle). The change of atmospheric concentrations during the considered period can be demonstrated by comparison of spatial distributions of γ -HCH air concentrations in 1990 (Figure 8.29, middle) and in 1996 (Figure 8.29, right). During this period air concentrations were reduced almost everywhere in Europe. Some increase of air concentrations in France is caused by the increase of γ -HCH usage in the country (Pacyna et al., 1999).

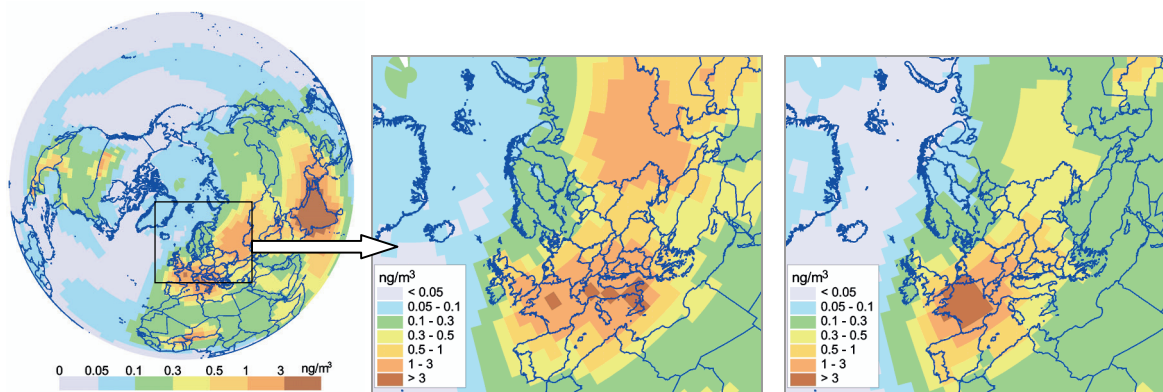


Figure 8.29 Spatial distribution of γ -HCH air concentrations in the Northern Hemisphere in 1990 (left) and in the EMEP domain in 1990 (middle) and in 1996 (right), ng/m³.

Intercontinental transport. The contributions of different emission sources to γ -HCH deposition to selected European regions are given in Figure 8.30. Contribution of non-European emission sources could be considerable. For example, 5% of depositions to North Europe is explained by Indian γ -HCH sources.

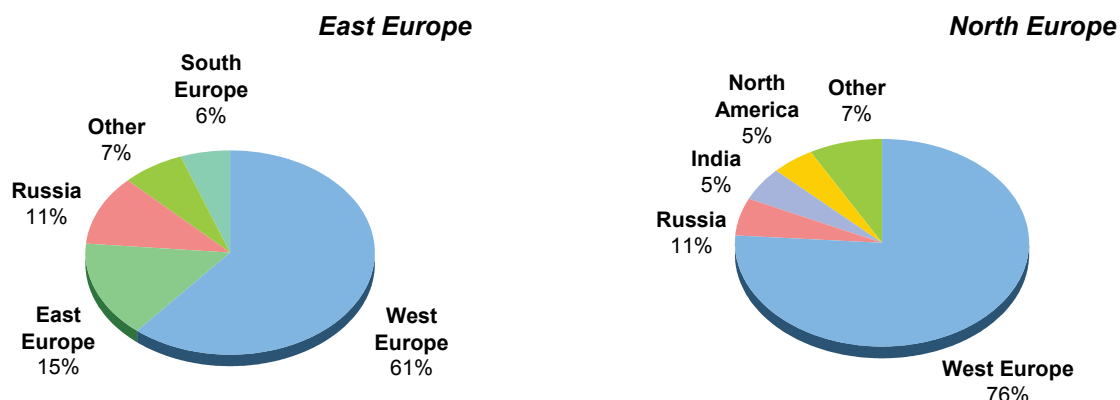


Figure 8.30 Contributions of γ -HCH emission sources to depositions to the selected European regions in 1996, %.

Arctic pollution. In general contamination levels in the Arctic are less than in Europe by an order of magnitude or more. However, in some parts of the Arctic contamination levels can be comparable with those in Europe. Maximum contributions to the Arctic pollution by γ -HCH are made by emission sources of West Europe (about 40%). Then follow Indian sources (19%) and North American sources (17%). The contributions of all other groups of sources are about 10% or less (Figure 8.31).

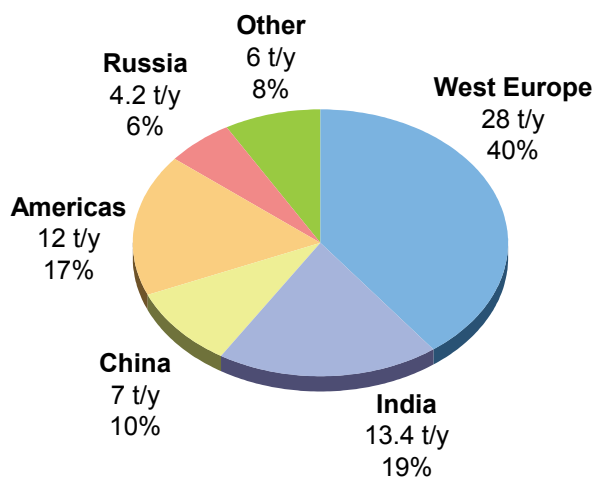


Figure 8.31 Contributions of γ -HCH source groups to the deposition to the Arctic region in 1996, t/y (%).

8.4 Conclusions

During the period from 1980 to 2000 high reduction of POP emissions in Europe took place (about 7 times for PCBs, 5 times for PCDD/Fs and 2 times for PAHs). Consequently, atmospheric concentrations of these pollutants are also essentially decreased. However, due to high accumulation capacities of such environmental compartments as soil and seawater and high persistence of POPs in these media the problem of POP contamination of these media is still very important. For instance, the bulk of PCDD/Fs, PAHs and PCBs is contained in soil (up to 90% of total amount in the environment), and very large fraction of γ -HCH is accumulated in seawater (more than 80%). The decrease of contamination of these media lags behind emission reduction by several decades.

Transboundary transport plays an important role in the forming of the pollution in Europe. For PAHs transboundary contributions range from 30 to 80% in different European countries. For some POPs (PCBs, γ -HCH, HCB), the correct evaluation of pollution in Europe requires the account of emission sources of the whole Northern Hemisphere. Modeling the POP transport and accumulation on the hemispheric scale allows one also to evaluate the contributions of European emission sources to the pollution of such vulnerable ecosystems as the Arctic and other continents.

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