TNO Built Environment and Geosciences

Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek / Netherlands Organisation for Applied Scientific Research

Laan van Westenenk 501
P.O. Box 342
7300 AH Apeldoorn
The Netherlands

www.tno.nl

P +31 55 549 34 93
F +31 55 541 98 37

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Study to the effectiveness of the UNECE Persistent Organic Pollutants (POP) Protocol and cost of additional measures

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

Date	July 2006
Authors	H.A.C. Denier van der Gon A.J.H. Visschedijk M. van het Bolscher
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Preface

The 1998 Persistent Organic Pollutants (POP) Protocol under the UNECE Convention on Long-range Transboundary Air Pollution entered into force 23 October of 2003 implying the start of the review of the Protocol. The review focuses on the sufficiency and effectiveness of the Protocol. In December 2005 the Executive Body decided the ‘Sufficiency and Effectiveness Review’ as drawn up and delivered by the Task Force on Persistent Organic Pollutants complete. However, the Executive Body did not yet decide to finalise the review and to start the revision of the POP Protocol.

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

This report presents results of the second phase of the project addressing further emission reductions and incremental costs of possible additional measures, after complete implementation of the current POP Protocol. The second phase of the TNO project already anticipates on a possible revision of the POP Protocol. This report shows that substantial further emission reductions are possible. Therefore, I hope the Executive Body in December 2006 decides the review to be complete and to also decide to ask the Working Group on Strategies and Review to start the revision of the Protocol.

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

Hans Bolscher
Director Climate Change and Industry

Summary and Conclusions

The 1998 UNECE Protocol for Persistent Organic Pollutants (POP) entered into force on October 23, 2003. In the review of the Protocol, an assessment of the emission reduction and implementation costs of a possible revised Protocol will be needed. The Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has commissioned TNO to execute a study on the effectiveness of the UNECE POP Protocol and cost of additional measures consisting of two phases. Phase I comprised an emission inventory for the base year 2000, projections for 2010-2015-2020, geographical allocation of these emissions, efficiency of the current Protocols and an inventory of additional reduction measures (Denier van der Gon et al., 2005). The present reporting is the second phase of this study and comprises an estimation of the emission reduction as well as costs of options for a possible revision of the 1998 UNECE POP Protocol involving the POPs listed in the Protocol as well as substances that may be proposed for addition of the Protocol. The rationale is that during the review of the POP Protocol there will be a need for an assessment of the potential for further emission reduction and costs of a possible revision of the Protocol.

The sources of POPs listed in the Protocol that are to be addressed for a possible revision of the POP Protocol have been selected based on a key source analysis of the projected remaining emissions upon full implementation of the POP Protocol in 2020, with the exception of emissions from domestic / residential sources. In consultation with the commissioner of the project it has been decided not to evaluate the potential of emission reduction by addressing residential /domestic combustion sources although there emissions may be relevant. The main motivation for this choice is the foreseen difficulties in legislation, implementation and enforcement of relevant emission control measures.

Generally speaking, the measures for POPs or substances emitted as unintentional by-products consist of implementing emission reduction technologies, end-of-pipe measures or fuel switches. The emissions from POPs or substances released due to product use can usually be replaced by an alternative substance (or in some cases replacing the entire product e.g. replacing fungicide-treated wood by plastic or metal). Emission reduction beyond full implementation of the 1998 UNECE POP Protocol is investigated for the POPs (Hexaclorobenzene (HCB), Dioxins and furans (PCDD/F), PCB and Lindane). Furthermore, five substances proposed for addition to the POP Protocol (Pentabromodiphenyl ether (PeBDE), Pentachlorobenzene (PCBe), Short chained chlorinated paraffin’s (SCCP’s), Polychlorinated naftalenes (PCN) and Hexachlorobutadiene (HCBD)) are addressed as well as three substances that may possibly be proposed for addition (Dicofol, Endosulfan, Pentachlorophenol (PCP)). This does not cover all substances proposed for addition as PFOS and OctaBDE have recently been proposed for addition to the POP Protocol. These substances are only superficially discussed in this report as the proposal of these substances was not envisaged at the start of the present study.

The potential measures and their associated costs for emission reduction of POPs and the substances listed above are discussed in detail by substance and avoided emissions as well as national remaining emissions after a possible revision of the POP Protocol are quantified. The result of a revised POP Protocol following the selected measures are aggregated for UNECE-Europe for the unintentional released by-products (Table S1 and Table S2) and emissions due to product use (Table S3).

Emissions due to unintentional released by-products

The measures implemented in a possibly revised Protocol to further reduce the emission of PCDD/F released as unwanted by-products include the injection of activated carbon for electric arc furnaces and introducing an emission limit value (ELV) of 0.5 ug Teq/Nm^3 (that also applies to certain other types of waste incineration) for incineration of non-hazardous industrial waste. These two measures for PCDD/F have co-benefits for other substances (HCB, PCB and PCN, Table S1). Moreover, the injection of activated carbon has co-benefits for (gaseous) mercury emission reduction in case the abated PCDD/F source is also a Hg source. Costs shown in Table S1 will not be equally distributed over all countries, this depends on whether particular industrial processes are carried out in each individual country.

Table S1 Costs of a possible revision of the POP Protocol for emission of unintentional by-products by source category in UNECE-Europe.

Category	Proposed measure	Costs (M€/yr)	Substance	Avoided Emission
Industrial solid waste incineration	Further tightening of ELVs for PCDD/F (0.5 ug Teq/Nm^3)	200	PCDD/F (g Teq/yr) PCB (kg/yr) HCB (kg/yr) *PCN (kg/yr)*[a)]	535 74.4 153 143
Electric arc furnaces	Injection of activated carbon following BAT	928	PCDD/F (g Teq/yr) *PCN (kg/yr)*[a)]	520 31
Magnesium production	Injection of activated carbon	3.4	*HCBD (kg/yr)*[a)]	2401
Secondary aluminium production	Alternative degassing agents not causing HCB emissions	0	HCB (kg/yr)	1124

[a)] PCN and HCBD are not included in the 1998 POP Protocol

Table S2 Emission of unintentional by-products in 2020 in the EU25+ and Non-EU25+ after full implementation of the POP Protocol, avoided emission by substance and estimated remaining emission after implementation of a possible revision of the POP Protocol.

Substance	**Emission FIPOP 2020**		**Avoided Emission**		**Remaining emission**	
	EU(25)+	**Non-EU25+**	**EU(25)+**	**Non-EU25+**	**EU(25)+**	**Non-EU25+**
PCDD/F (g Teq/yr)	2059	1730	710	345	1350	1385
PCB (kg/yr)	3777	3637	73.8	0.6	3703	3637
HCB (kg/yr)	1398	124	1217	60	181	65
HCBD (kg/yr)	1446	1148	1326	1075	120	73
PCN (kg/yr)	179	103	133	41	46	63

Numbers may not add up exactly due to rounding to no decimals

The costs and avoided emission of measures aiming at PCDD/F emissions in Industrial waste incineration (IWI) (Table S1) appear most attractive but are in the same order of magnitude as measures for electric arc furnaces (EAF). The local conditions as well as activity data for industrial waste incineration are rather uncertain and emission data from EAF are uncertain so, the figures should be interpreted with care. Keeping these limitations in mind Table S1 can be interpreted as follows;

– IWI costs are ~200 M€ reducing 535 g Teq PCDD/F, 143 kg PCN, 74 kg PCB and 153 kg HCB
– EAF costs are ~928 M€ reducing 520 g Teq PCDD/F and 31 kg PCN.

Thus, the cost effectiveness of PCDD/F emission reduction in a revised POP Protocol would be for 0.37 M€/g Teq and 1.8 M€/g Teq for industrial waste incineration and electric arc furnaces, respectively. This is considerably more expensive than PCDD/F emission reduction in the current POP Protocol as estimated by Berdowski et al. (1998). Thus the comparison indicates that the cost-effectiveness of the 1998 POP Protocol is more favourable than further reduction starting after full implementation of the POP Protocol. However, this is not surprising as any sensible emission reduction strategy will start with first implementing the most cost-effective measures.
A further additional reduction of HCB emissions can be achieved in the secondary aluminium industry by the (assumed) cost-neutral replacement of chlorine compounds as degassing agents (Table S1). If HCBD would be included in the revised POP Protocol, the potential exists to reduce ~ 2100 kg HCBD emission from primary magnesium production at an annual cost of about 3M€.

Emissions due to product use

Emissions of substances due to product use can be effectively reduced by using alternative substances in the production process or changing to alternative products. The measures considered thus imply replacement and a ban on the use of these substances. For two POPs (PCB and HCB) and two substances possibly proposed for addition to the POP Protocol (PeBDE and PCP) we estimated that such a replacement of the substance in product use could be more or less cost-neutral. For the POP Lindane, and the substances Dicofol, Endosulfan, SCCPs replacement will not be cost-neutral (Table S3). The costs for replacement of dicofol and endosulfan are expected to be highest in Italy, Spain, France, Greece, Turkey, Ukraine and Russia. However, cost estimates for Turkey, Ukraine and Russia are surrounded by a large uncertainty because of uncertainties in usage data.

Table S3 Usage of Lindane, Endosulfan, Dicofol, and SCCPs in UNECE Europe and estimated replacement costs due to a possible revision of the POP Protocol.

Substance		**Type of measure**	**Usage**	**Cost (M€/yr)**	
			(tonnes/yr)	**Lower**	**Upper**
Lindane	- Seed Treatment	Replacement / ban	41	0.5	
	- Soil Incorporation		41	2.3	
	- Wood Preservation		419	6.7	
Endosulfan		Replacement / ban	1550	31	160
Dicofol		Replacement / ban	317	28	129
SCCPs		Replacement / ban	67877	7	170

PCB, HCB, PeBDE and PCP are not shown in this table because replacement of current usage is cost-neutral and emission is not related to current usage but released from in-use products with a long service life and/or may be emitted from product use in imported goods

The average cost effectiveness for Lindane as determined by this work is 36 €/kg avoided air emission. This is lower than the cost-effectiveness estimated in an earlier study by Berdowski et al. (1998) who reported 64 – 120 €/kg avoided emission. This is remarkable as it is to be expected that most cost-effective measures will be implemented first. However, as stated earlier, the comparability between both studies is limited due to different starting points and conditions. The difference is caused by the assumption in the present study that replacement by an alternative substance for the currently allowed usage will not result in increased application frequency of the substance. If replacement of a substance results in a higher labour demand, these costs rapidly dominate the total replacement costs in Europe. Since the Berdowski (1998) study different alternative substances and/or techniques which may help in a more effective replacement of Lindane have become available. However, it should be realized that the assumptions are quite arbitrary and may require a more in-depth analysis.

Final remarks and discussion

Obtaining reliable, general applicable, cost data is difficult if not impossible because new cost data may not be comparable with the existing information in the POP Protocol and cost data are usually case-specific or country-specific, especially for the emissions due to unintentional releases. Thus the costs of emission reduction as indicated in this study gives an order of magnitude of the cost range for a specific technology. It allows only a limited comparison of costs between techniques and countries. An important further complication is the attribution of costs when several policies move in the same direction. In this study we have omitted all costs due to so-called autonomous developments. This is a matter of definition because autonomous developments involve costs as well. The implementation of an EC Directive with a certain emission limit value on a certain source in an EC country brings about exactly the same costs as implementation of that same ELV for the same source elsewhere to implement a revised POP Protocol, provided all other parameters are equal. In this study, the costs made to fulfil the obligation to another Protocol or Directive are not attributed to the revision of the POP Protocol if the obligation to comply with this other policy takes place in an earlier point in time. Nevertheless, these costs will have to be made. Hence the costs for, for example, phasing out of SCCPs in this study are mainly located in the non-EU25+ countries, only because these costs are expected to be made earlier in the EU25+ to comply with an EC Directive. The motivation to not include these costs is that even if it would be decided not to revise the POP Protocol, these costs would still be made by autonomous development.

When calculating the costs per tonne of emission prevented, all costs for a specific measure will be taken into account despite the fact that a measure may generate emission reduction for other substances as well. This is a necessity because it is at present not possible to weigh emission reduction of one POP compared to emission reduction of another POP or other harmful elements (e.g. heavy metals). For example, the measures that will be implemented to comply with tightening of the emission limit values (ELV) for PCDD/F as outlined in this study will also reduce other POP emissions (e.g. PCN, PCB, HCB; Table S1) and for some sources also gaseous mercury emissions. Since the co-benefits of the measures are not accounted for in the costs, one may argue that the costs are overestimated.

Next to the substances covered in the present study, OctaBDE and PFOS have recently been proposed for addition to the UNECE POP Protocol. It is recommended that for these substances a similar emission inventory be made, including the releases from in-use products. Additional studies for a revision of the POP Protocol remain necessary as new insights may change the priorities of addressing the release of substances with POP characteristics into the environment.

Table S4 UNECE emissions of POPs and substances that are (possibly) proposed for addition to the POP Protocol after full implementation of the POP Protocol (FIPOP) and after full implementation of additional measures (FIPOP+AM) as proposed in this study and estimated costs of additional measures.

POP	**Projected emission**		**Costs**	**Substance**	**Projected emission**		**Costs**
	FIPOP	**FIPOP+AM**			**FIPOP**	**FIPOP+AM**	
	Tonnes/yr		**(M€/yr)**		**Tonnes/yr**		**(M€/yr)**
HCB	1.5	0.25	0	HCBD	2.6	0.19	3.4
HCH	255	0	9.5	PBDE	9.8	0[c]	0
PCB	7.4	7.3	0[e]	PCN	0.28	0.11	0[e]
PCDD/F	3.8[a]	2.7	1128	PeCB	0	0	0
BaP	597	-[b]	-	SCCP	114	0	7 – 170
BbF	678	-[b]	-	*Dicofol*[d]	32	0	28 – 129
BkF	222	-[b]	-	*Endosulfan*[d]	775	0	31 – 160
Indeno	460	-[b]	-	*PCP*[d]	705	207	0

[a] PCDD/F in kg Teq/yr

[b] PAH indicator compounds are not addressed by the additional measures because the key sources are residential/domestic sources which are not considered in this study (see text)

[c] Implementation of additional measures is assumed to start in 2010. Under this assumption no emissions from in-use products of PeBDE remain and 1/3 of PCP emissions of in-use products still remain.

[d] Substances not yet proposed for addition to the POP Protocol

[e] No costs; Emission reduction is side-effect of measures aimed at other substances

The further emission reduction achieved by a possible revision of the POP Protocol is placed in perspective by comparing the remaining emissions of the relevant POPs for the years 2000, 2020 assuming full implementation of the 1998 UNECE POP Protocol and 2020 assuming full implementation of a revised POP Protocol according to the measures proposed in this study. This comparison suggests for several POPs that the further reduction from POPs already addressed in the 1998 POP Protocol is limited because full implementation of the current Protocol already reduced the majority of the emissions. A bigger impact appears possible by incorporating new substances in the Protocol and subsequently phase out the usage of these substances. Although we believe it to be true, this is a rather qualitative and arbitrary statement because it is (at present) not possible to compare the harmfulness of individual substances.

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1. Introduction

Persistent organic pollutants (POPs) are organic compounds that, to a varying degree, resist photolytic, biological and chemical degradation. POPs are often halogenated and characterised by low water solubility and high lipid solubility, leading to their bioaccumulation in fatty tissues. They are also semi-volatile, enabling them to move long distances in the atmosphere before deposition occurs. In 1998 the UNECE Protocols for Heavy Metals (HM) and Persistent Organic Pollutants (POP) were signed by 35 countries and the European Commission. The Protocols enter into force 90 days after ratification by a minimum of 16 countries. As a result of this the POP Protocol has entered into force on October 23, 2003 and the HM Protocol entered into force on December 30, 2003. In 2003 the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has asked TNO to execute a study consisting of two phases.

- Phase I of the study was completed in August 2005 and comprises the construction of an emission inventory for the year 2000, including actualisation of emission data and projections for 2010-2015-2020, geographical allocation of these emissions, efficiency of the current Protocols and a preliminary inventory of additional reduction measures (Denier van der Gon et al., 2005).
- Phase II comprises an estimation of the emission reduction as well as costs of options for a possible revision of the HM/POP Protocols. The options to be considered in Phase II are amongst others based on the work done by and information submitted to the TFPOP under the leadership of Canada and the Netherlands (http://www.unece.org/env/popsxg/pops_xg.htm). This includes e.g. Compendium of substance-related information, dossiers of information on substances not included in the Protocol and documents on exploration of management options for substances (e.g. PeBDE, PFOS)

The rationale behind Phase II is that during the review of the HM and POP Protocols, scheduled to take place after the entry into force of the Protocols, there will be a need for an assessment of the potential for further emission reduction and costs through possible revision of the Protocols.

1.1 Scope of the study

The study aims to propose options to revise the POP Protocol and the annual cost and emission reduction due to a possibly revised POP Protocol is to be estimated. The possible revision of the POP Protocol includes among others the possibility of adding several new substances to the POP Protocol. The emission reduction and costs of the selected measures will be estimated for the year 2020. Total annual cost by measure, by sector and by country, and the emission reduction by substance will be presented.

1.2 Substances and Countries covered by the study

The substances covered by the present study are listed in Table 1. An emission inventory of these substances for UNECE-Europe is reported in Denier van der Gon et al. 2005, including simple estimation methodologies for the substances possibly proposed to be added to the POP Protocol. The emission inventory and reporting followed the guidelines given in the POP Protocol (ECE/EB.AIR/60). This implies that for the group of polycyclic aromatic hydrocarbons (PAHs) four indicator compounds were inventoried: benzo(a)pyrene,benzo(b)fluoranthene, benzo(k)fluoranthene, and indeno(1,2,3-cd)pyrene, as specified in Annex III of the POP Protocol (ECE/EB.AIR/60). For dioxins and furans (PCDD/F) the emissions of different congeners are given in toxicity equivalents (TE), no individual species emissions are given. For ten of the Persistent Organic Pollutants addressed by the UNECE POP Protocol (Aldrin, Chlordane, Chlordecone, DDT, Dieldrin, Endrin, Heptachlor, Mirex, Toxaphene, and HBBP) emissions are no longer occurring. These substances are not further addressed in the present report. The substances listed in the right column of Table 1 are or may be proposed for addition to the POP Protocol (Table 1, not yet proposed substances in italics). Recently OctaBDE and PFOS have been proposed for addition but they were not yet considered at the start of this study. However, some remarks on these substances will be made in chapter 3 based on information of the dossiers submitted to UNECE.

Table 1 Substances addressed in the present study.

Persistent Organic Pollutants listed in the UNECE POP Protocol	**Substances (*possibly*) proposed to be added to the POP Protocol**[a]
Aldrin	Hexachlorobutadiene (HCBD or HBU)
Chlordane	Pentabromodiphenyl ether (PentaBDE, PeBDE[d])
Chlordecone	Pentachlorobenzene (PCBe)
Dieldrin	Polychlorinated naftalenes (PCN)
Endrin	Short chained chlorinated paraffin's (SCCP's)
Hexabromobiphenyl (HBBP)	*Dicofol*
Mirex	*Endosulfan*
Toxaphene	*Pentachlorophenol (PCP)*
DDT	
Heptachlor	
Polychlorinated biphenyls (PCBs)	Octabromodiphenyl ether (OctaBDE)[e]
Hexachlorocyclohexane (HCH), including lindane	Perflourooctane sulfonates (PFOS)[e]
Dioxins and Furans (PCDD/F)[b]	
Polycyclic aromatic hydrocarbons (PAHs)[c]	
Hexachlorobenzene (HCB)	

[a] Substances not yet proposed for addition to the Protocol (Dicofol, Endosulfan and PCP) are marked with Italics

[b] Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF).

[c] Four indicator compounds shall be used: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k) fluoranthene, and indeno(1,2,3-cd)pyrene, as specified in Annex III of the POP Protocol (ECE/EB.AIR/60).

[d] The acronym PBDE may cause confusion as it is used for Pentabromodiphenyl ether as well as Polybromodiphenyl ethers. In this study only PentaBDE is addressed.

[e] OctaBDE and PFOS were not foreseen as candidates for addition to the POP Protocol at the start of the present study, only limited information is provided based information submitted to the TFPOP.

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

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

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

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

1.3 Structure of the report

The methodology of the study is outlined in chapter 2. This includes source selection and a brief presentation op the projected remaining emissions in 2020 after full implementation of the POP Protocol which is the starting point of this study. Chapter 3 discusses the potential measures and their associated costs for emission reduction of POPs and substances by substance and by source type. The results are presented and discussed in chapter 4. Conclusions from this work are in fact the summarized results. Therefore these are integrated into a “summary and conclusions” chapter presented at the beginning of this report.

2. Methodology

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

2.1 UNECE POP emissions in 2020 and autonomous measures considered

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

- The 1998 UNECE POP Protocol (all countries; including implementation of BAT).
- The UNECE Protocols for substances other than POP such as the 2nd Sulphur Protocol (as far as relevant for POP).
- Integrated Pollution Prevention and Control (IPPC) EC Directive.
- EC Directive on the incineration of waste.
- National policies and EC policies, such as elimination or restriction of the use of a certain chemical and/or emission limit values for stationary sources.
- Measures agreed internationally by the industry, as there can be mutual agreements to reduce air emissions in specific braches.

Specific emerging policies addressing a specific substance that influence the amount of remaining emissions for substances possibly proposed to be added to the Protocol will be discussed in a respective subsection for each substance in chapter 3. The basis for calculation of potential emission reductions upon revision of the UNECE POP Protocol are the emissions summarized by country in Table 3 and Table 4.

Table 3 Projected annual emissions of POP in UNECE-Europe by country in 2020 following IIASA CLE-BL scenario and assuming all UNECE countries implement the POP Protocol before 2010. (kg/yr, PCDD/F in kg Teq/yr) (Denier van der Gon et al, 2005).

ISO3	**HCB**	**HCH**	**PCB**	**PCDD/F**	**PAH indicators**			
					BaP	**BbF**	**BkF**	**Indeno**
ALB	0	123	0	0.00	2202	2898	948	1589
ARM	0	0	0	0.00	2344	3079	1023	1665
AUT	38	0	49	0.03	22823	29840	9814	16427
AZE	0	0	0	0.02	4928	6535	2173	3544
BEL	2	167	58	0.03	2101	2616	882	1619
BGR	30	0	126	0.14	3438	4462	1470	2569
BIH	0	115	46	0.01	1889	2500	903	1340
BLR	0	0	1	0.01	306	411	71	477
CHE	3	0	4	0.01	541	694	249	397
CYP	0	0	1	0.00	1724	2286	752	1238
CZE	13	0	147	0.32	7999	10266	3368	6049
DEU	493	0	903	0.18	36102	46530	15978	25530
DNK	18	0	12	0.05	2566	3402	1197	1814
ESP	28	9962	29	0.09	1540	1667	742	1428
EST	0	0	39	0.00	1206	1590	533	925
FIN	18	0	44	0.03	11198	14643	4886	8001
FRA	273	39859	216	0.33	56195	73065	24667	39914
GBR	6	30308	1124	0.10	4022	2951	2137	1437
GEO	0	0	0	0.01	3465	4552	1490	2497
GRC	0	2431	132	0.04	7144	9281	3373	4975
HRV	0	6983	9	0.06	1669	2206	715	1248
HUN	19	0	62	0.07	2866	3719	1218	2139
IRL	0	0	7	0.01	2192	2872	931	1739
ISL	0	0	0	0.00	352	375	291	106
ITA	244	143856	146	0.13	22144	28533	9814	16040
KAZ	0	0	313	0.07	17105	23012	8075	12700
KGZ	0	0	7	0.01	4795	6324	2116	3423
LTU	0	0	16	0.04	1658	2159	698	1466
LUX	0	0	1	0.01	139	183	42	114
LVA	0	0	2	0.01	1410	1854	638	1210
MDA	61	0	10	0.00	412	498	229	1035
MKD	0	87	25	0.00	1080	1431	471	799
NLD	84	0	46	0.03	2216	2366	1302	1535
NOR	127	0	6	0.04	12149	3960	2457	1788
POL	6	0	519	0.14	11621	13502	2956	15510
PRT	5	7729	30	0.31	12896	16940	5572	9238
ROM	1	1052	136	0.11	4430	5585	1926	3379
RUS	0	0	1969	0.85	248620	253693	78883	192881
SVK	0	0	123	0.03	1697	2098	792	1151
SVN	0	0	19	0.00	386	502	172	282
SWE	21	0	44	0.03	7122	9233	3155	5048
TUR	0	11806	323	0.24	30331	38685	12247	24487
UKR	32	0	429	0.17	29778	27295	7742	35164
YUG	0	510	243	0.02	5813	7729	2591	4217
Grand Total [a]	1.52	255	7.3	3.8	597	678	222	460

[a] tonnes/yr, PCDD/F in kg Teq/yr.

Table 4 Projected annual emissions of substances (possibly) proposed to be added to the POP Protocol in UNECE-Europe by country in 2020 assuming all UNECE countries implement the POP Protocol before 2010 (kg/yr) (Denier van der Gon et al, 2005).

ISO3	**HCBD**	**PBDE**	**PCN**	**PeCB**	**SCCP**	***Dicofol***	***Endosulfan***	***PCP***
ALB		41	0	0	869	38	1254	1308
ARM		39	0	0	837	87	173	1259
AUT		95	3	0	92	0	750	1074
AZE		91	1	0	1939	123	3640	2917
BEL		121	1	0	116	20	9050	8
BGR		92	17	0	1957	883	4204	2946
BIH		45	0	0	960	22	1168	1444
BLR		122	1	0	2595	0	14956	3903
CHE		86	0	0	82	0	3800	963
CYP		9	0	0	190	142	2543	286
CZE	8	121	6	0	2570	76	1272	3867
DEU	236	967	9	0	932	0	0	10885
DNK		63	1	0	61	0	0	707
ESP	8	471	7	0	0	12500	110500	106
EST		17	0	0	358	2	26	539
FIN		61	11	0	59	0	0	685
FRA	338	699	74	0	673	1400	35400	19807
GBR	18	700	4	0	675	100	500	449211
GEO		59	0	0	1256	0	1882	1890
GRC		124	2	0	120	0	36900	3976
HRV		50	8	0	1072	0	1280	1613
HUN		119	3	0	2537	532	3356	3817
IRL		45	1	0	43	0	0	275
ISL		3	0	0	69	0	9	104
ITA	8	679	14	0	654	9524	45300	7643
KAZ	208	197	4	0	4188	69	7076	6300
KGZ		55	1	0	1173	43	3538	1764
LTU		43	2	0	906	0	61	1363
LUX		5	0	0	5	8	65	165
LVA		28	1	0	0	0	26	906
MDA		52	1	0	1109	0	4939	1668
MKD		24	0	0	511	159	891	769
NLD		187	1	0	180	0	0	24000
NOR	828	53	1	0	0	0	0	595
POL		455	10	0	9672	0	4939	14551
PRT		118	15	0	114	486	1500	17054
ROM		264	6	0	5619	1469	10717	8454
RUS	908	1718	43	0	36540	368	212704	54973
SVK		64	1	0	1352	105	1133	2033
SVN		23	0	0	482	92	856	726
SWE		105	11	0	101	0	0	1183
TUR		773	12	0	16435	2476	120322	24725
UKR	8	578	9	0	12302	596	123219	18507
YUG	24	125	1	0	2669	382	5199	4015
Total (tonnes/yr)	2.6	9.8	0.28	0.0	114	32	775	705

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

The contribution of the individual source sectors after full implementation of the POP Protocol and implementation of foreseen autonomous measures in 2020 has been calculated for the total UNECE Europe domain (Table 5). The emissions of the POPs; Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Hexabromobiphenyl, Mirex, Toxaphene, DDT, Heptachlor en PCBe are estimated to be zero or negligible in 2000 and 2020 (Denier van der Gon et al., 2005) and no further assessment is needed for these substances. For the remaining substances listed in the POP Protocol the relative contribution by source sector is given in Table 5, together with an indication by shading text if the emission reduction achieved by the present POP Protocol is large. It is concluded that;

- A further emission reduction on top of the present POP Protocol is not considered for PCB and PCN because the PCB emissions have been almost fully reduced by full implementation of the current POP Protocol and PCN emissions are addressed by the measures for PCDD/F (see also Denier van der Gon et al., 2005).
- For HCH (including lindane) the current POP Protocol will not result in (significant) further reduction and alternative measures will be proposed. The remaining uses to be addressed are only for lindane, other HCH isomers are no longer used.
- For PCDD/F the only remaining sources apart from domestic sources are ‘Industrial Waste Incineration’ and ‘Electric Arc Furnaces’. For these sectors costs and benefits of a possible further reduction of emission limit values, next to the existing obligation in the POP Protocol to implement BAT, will be assessed.
- For PAHs it can be concluded that the most relevant source is wood burning in domestic / residential heating (Table 5). There is basically no room for further industrial emission reduction other than the measures already proposed in the POP Protocol. Emission limit values for domestic sectors are not considered in the present study because it is felt that legislation, compliance and enforcement of such measures is too complicated and beyond the scope of the present study.
- The costs and benefits of reducing HCB emissions from secondary Aluminum production will be assessed.

2.2.1 Substances possibly proposed for addition to the POP Protocol

For pesticides (Dicofol, Endosulfan), the fungicide PCP and the substances used in products (PeBDE en SCCPs) costs of alternatives will be estimated for the source sectors dominating the emissions in Table 5. The remaining emission of PCN after full implementation of the POP Protocol is very low. No further emission reduction measures for PCN will be proposed. PCN emission will decrease further due to implementation of some additional PCDD/F measures (see above). The emission reduction resulting from PCDD/F measures for PCDD/F will be quantified. For

HCBD costs and benefits of reducing emission from the Mg producing industry will be assessed.

Table 5 *Contribution of the individual source sectors after full implementation of the POP Protocol and implementation of foreseen autonomous measures in 2020 for total UNECE Europe.*

Source Category	Fuel	PCB	HCH	PCDD/F	BaP	BbF	BkF	Indeno	HCB	Dicofol	Endosulfan	HBU	PBDE	PCBe	PCP	PCN	SCCP	BAT Review	ELV Review	TNO [a]
Heat / Power Plants	Solid fuels	**56%**		**10%**	0%	0%	0%	0%								3%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
Heat / Power Plants	Liquid fuels			3%	0%	0%	0%	0%								1%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
Oil Refineries	Solid fuels	1%		0%	0%	0%	0%	0%								0%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
	Liquid fuels			0%	0%	0%	0%	0%								0%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
Solid Fuel Production	Solid fuels	0%		1%	1%	1%	0%	2%								1%		**X**		
	Liquid fuels			0%	0%	0%	0%	0%								0%		**X**		
Residential, commercial and other combustion	Solid fuels	4%		**11%**	**10%**	**9%**	3%	**24%**								**7%**		**X**	Limit for CO	**X**
	Liquid fuels			4%	0%	0%	0%	0%								3%		**X**		**X**
	Wood			**25%**	**72%**	**83%**	**84%**	**66%**	3%							**14%**		**X**	0.1-0.5ng/m3 (PCDD/F); 10mg/m3 (BaP)	**X**
Industrial Combustion	Solid fuels	**7%**		4%	0%	1%	2%	1%								3%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
	Liquid fuels			2%	0%	0%	0%	0%								1%		>50MWth	>50MWth, 0.1-0.8ngTEQ/m3 (PCDD/F); 0.2mg/m3 (BaP); 0.2mg/m3 (HCB)	
Coke Ovens	-				3%	1%	3%	2%										**X**	0.1ng/m3 (PCDD/F); 0.05-0.2mg/m3 (BaP)	
Iron & Steel, Sinter Production	-	**11%**		3%					0%							2%		0.01-0.5ngTEQ/m3 (PCDD/F)	0.1-2.5ngTEQ/m3 (PCDD/F); 0.05mg/m3 (BaP)	
Iron & Steel, Oxygen Furnace	-	**14%**														0%		0.01-0.5ngTEQ/m3 (PCDD/F)	0.1-5ngTEQ/m3 (PCDD/F); 0.05mg/m3 (BaP)	
Iron & Steel, Electric Arc Furnace	-			**17%**	0%											**14%**		0.01-0.5ngTEQ/m3 (PCDD/F)	0.1-5ngTEQ/m3 (PCDD/F); 0.05mg/m3 (BaP)	**X**
Iron & Steel, Open Hearth Furnace	-	0%														0%				
Soederberg Aluminium	-				**10%**	1%	3%	0%										**X**	0.1ng/m3 (PCDD/F); 0.05mg/m3 (BaP)	
Pre-baked Aluminium	-				1%	1%	3%	0%												
Secondary Aluminium Production									**82%**									0.01-0.5ngTEQ/m3 (PCDD/F)	0.1-5ngTEQ/m3 (PCDD/F); 0.05mg/m3 (BaP)	**X**
Primary Copper Production																		0.01-0.5ngTEQ/m3 (PCDD/F)	0.1-1ngTEQ/m3 (PCDD/F); 0.05mg/m3 (BaP)	
Secondary Copper Production	-			0%												0%		0.01-0.5ngTEQ/m3 (PCDD/F)		
Secondary Lead Production	-			0%												0%				
Production of Primary Magnesium	-											**97%**								**X**
Chemical Industry: Production of PUR	-												3%							
Oil and Gas Extraction	Liq. & gas. Fuels			0%	0%	0%	0%	0%								0%				
Road Transport (Exhaust)	Gasoline				0%	0%		0%												
	Diesel				2%	2%		2%												
Domestic Air Transport	Gasoline			0%	0%	0%	0%	0%								0%				
	Kerosines			0%	0%	0%	0%	0%								0%				
Internal Navigation	Diesel			0%	0%	0%	1%	0%	0%							0%				
	Gasoline			0%	0%	0%	0%	0%								0%				
	Heavy Fuel Oil			0%	0%	0%	0%	0%	0%							0%				
	Kerosines				0%	0%	0%	0%								0%				
Non-specified Transport	Diesel			0%	0%	0%	0%	0%								0%				
	Gasoline			0%	0%	0%	0%	0%								0%				
	Heavy Fuel Oil			0%	0%	0%	0%	0%								0%				
	Kerosines			0%	0%	0%	0%	0%								0%				
Rail Transport	Solid fuels			0%	0%	0%	0%	0%								0%				
	Diesel			0%	0%	0%	0%	0%								0%				
	Kerosines			0%	0%	0%	0%	0%								0%				
	Heavy Fuel Oil			0%	0%	0%	0%	0%								0%				
Municipal Waste Incineration	-	3%		0%					0%						0%	1%		0.01-0.1ngTEQ/m3 (PCDD/F)	0.1ngTEQ/m3 (PCDD/F)	
Industrial Waste Incineration	-	1%		**14%**					**10%**						0%	**51%**		0.01-0.1ngTEQ/m3 (PCDD/F)	0.1-0.5ngTEQ/m3 (PCDD/F)	0.1ngTEQ/m3 (PCDD/F)
Hazardous Waste Incineration	-	0%		0%					0%						0%	0%		0.01-0.1ngTEQ/m3 (PCDD/F)	0.1-0.2ngTEQ/m3 (PCDD/F)	0.1ngTEQ/m3 (PCDD/F)
Clinical Waste Incineration	-	0%		0%					0%						0%	0%		0.01-0.1ngTEQ/m3 (PCDD/F)	**X**	
Product uses in agriculture, industry and residential sector	-		**100%**	1%	0%	0%	0%	0%		**100%**	**100%**	3%	**96%**		**100%**		**100%**	**X**	**X**	**X**

Legend to table **Bold** Contribution > 5%
Text 2020 Emission very low compared to 2000: mostly no additional measures foreseen

[a] Denier van der Gon et al. (2005)

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

The starting point for the identification of measures to revise the POP Protocol and subsequent quantification of emission reductions and costs is the selection of sources based on contributions to the 2020 POP emissions assuming full implementation (all European UNECE countries) of the current POP Protocol and implementation of all foreseen autonomous developments (Table 3). The additional reduction in substance emissions due to a possible revision of the POP Protocol is partly determined by autonomous measures that are to be implemented depending on the obligations of each specific country. At several occasions the countries have been aggregated in two country groups; EU25 + (EU25 + Switzerland and Norway) and Non- EU25+ to facilitate the discussion because for some substances the foreseen autonomous reduction measures and policies that apply for each country are dominated by EC policies. The types of measures considered differ by type of emission. There are basically two types of emission sources, 1) emission of POP caused by the unintentional release of unwanted by-products and, 2) emission caused by the use of specific POP containing products (e.g. through evaporation after use) (Table 6).

Table 6 Classification of substances by source type.

Persistent Organic Pollutants	
Source type I - Unintentional release of unwanted by-products	**Source type II – product use**
Dioxins and furans (PCDD/F) PCB (minor contribution) PAHs [a] Hexaclorobenzene (HCB; also released through product use)	Hexaclorobenzene (HCB; also released as by-product) PCB HCH (including lindane) PAHs [a]
Substances (possibly) proposed for addition to the POP Protocol	
Source type I - Unintentional release of unwanted by-products	**Source type II – product use**
Polychlorinated naftalenes (PCN) Hexachlorobutadiene (HBU) (HCBD)	Pentabromodiphenyl ether (PentaBDE, PeDBE) Pentachlorobenzene (PCBe) Short chained chlorinated paraffin's (SCCP's) *Dicofol* *Endosulfan* *Pentachlorophenol (PCP)*

[a] four indicator compounds; Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno (1,2,3-cd)pyrene)

2.3.1 Emission due to unintentional by-products

The effect of emission control measures that address unintentional and unwanted by-products (Table 6, source type I) is complex to determine. Two categories of control measures exist here. The first comprises explicit emission limit values for certain substances and specific stationary sources as laid out in Directives or Protocols. The second category consists of a commitment to implement Best Available Technology (BAT) in a series of stationary sources.

The measures considered are presented in Table 7 by substance and will be discussed in detail in chapter 3.

Table 7 Emission measures proposed by substance for a possible revision of the POP Protocol in the present study.

Persistent Organic Pollutants	**Type of Measure**
Hexaclorobenzene (HCB)	Alternative product use not causing HCB emissions
Dioxins and furans (PCDD/F)	Further tightening of ELVs
PAHs	No measure proposed
PCB HCH (including lindane)	Replacement / Ban
Substances (possibly) proposed for addition to the POP Protocol[a)]	
Pentabromodiphenyl ether (PentaBDE, PeBDE) Pentachlorobenzene (PCBe) Short chained chlorinated paraffin's (SCCP's)) *Dicofol* *Endosulfan* *Pentachlorophenol (PCP)*	Replacement / Ban
Polychlorinated naftalenes (PCN)	No measure proposed – Additional benefits of PCDD/F emission reduction
Hexachlorobutadiene (HBU) (HCBD)	Implementing emission reduction technologies

[a)] Substances not yet proposed for addition to the POP Protocol in italics

2.3.2 Emission as a result of product usage

Control measures might involve the elimination of production and use of a substance. This type of control measure will result in the immediate elimination of direct emissions. However, emission from in-use products may still continue for a certain time. Emissions from in-use products with a long life time e.g. flame retardants in products, wood impregnated with fungicide, are often difficult to estimate due to a lack of emission factor data. Note that even after all direct emissions have ceased the substance may still be found in the ambient air many years, since all POP have the potential to be re-emitted. Re-emission is however not considered in this study, as is illegal use and leakage from stock piles. Emission control measures in the form of a usage restriction will stop direct emission of the specified banned usage but direct emission from exempted, allowed usage will continue.

2.4 Quantification of the impact of a possible revision of the POP Protocol

The uncertainty of the emission of a substance may be large due to uncertainty in emission factors or activity data. The impact estimation of emission control measures that address direct emissions is simple in the sense that implementation means immediate reduction. However, emissions from in-use products with a long life time e.g. flame retardants in products, wood impregnated with fungicide will only gradually reduce due to a phase out of the products containing the substance. It is therefore important to fix the date of entry into force of a possible measure. We have chosen to take the year 2010 as date of entry of a possible revision of the POP Protocol. This implies that if the usage of a certain substance is banned, direct emissions stop in 2010 but that products with an average lifetime of 10 years will only stop emitting the substance in 2020, products with an average life time of 15 years will in 2020 still emit (15-10)/15 of the in-use product emission level of 2010. The choice of year of entry into force is rather arbitrary. The advantage of 2010 over 2020 is that the effect of emission reduction can also be shown for substances that are mostly emitted from in-use products.

2.5 Spatial distribution of emission data

For the distribution of national country emission totals over the EMEP 50 x 50 km^2 grid, both point source information, population density and land use data have been used, as described in Denier van der Gon et al. (2005).

2.6 Activity data for year 2020

In the first phase of this study emission projection to the years 2010, 2015 and 2020 were made by considering the expected developments of source activity rates following the baseline scenarios developed by International Institute for Applied Systems Analysis (IIASA) in the framework of the Clean Air for Europe (CAFE) program (Amann et al., 2005; Baseline energy pathway, current legislation without climate policies: BL_CLE_Apr04 (Aug04)). For some source sectors that are important for POP emissions, no projections are made in the framework of the CAFE programme, for these sectors (e.g. waste incineration) a projection to 2010, 2015 and 2020 was made by TNO and described in Denier van der Gon et al. (2005). The emission projections were made by making scaling factors for the future years that were applied to the baseline year 2000 data.

3. Selected source-specific measures and/or substance-specific measures and their associated costs

Potential measures and the estimation of their associated costs are discussed in this chapter by source type. According to article 14.6 of the POP Protocol, Parties to the Protocol can propose new substances which can be added to annex I, II or III of the Protocol. A list of possible measures and associated costs that may be used for a revision of the POP Protocol is compiled in this chapter, following the source selection outlined in Chapter 2 for the persistent organic pollutants adopted by the UNECE POP Protocol, as well as possible measures and associated costs to reduce emissions for a number of substances that may possibly be proposed for addition to a revised POP Protocol (Table 1).

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

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

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

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

The annuity of the TCI is increased by the operational costs in order to come to the total annual costs. The operational costs, comprising fixed operational costs (maintenance, labour, other overhead costs, insurance etc.) and variable operational costs (energy, raw materials) are estimated by taking a percentage of the TCI. Strictly speaking running costs are dependant on the emission control technique that is used, for instance fabric filters have a somewhat higher operational cost due to frequent replacement of the filter cloth. These differences are however neglected due to the overall uncertainty of the cost estimates and a fixed percentage, being 5%, (4% for the fixed operational costs and 1% for the variable operational costs

(Berdowski et al., 1998)), has been used in order to estimate the total operational costs.

The costs of possible revision of the POP Protocol are calculated as additional costs on top of the costs of the present POP Protocol (Incremental cost). This implies that the difference between the present ELV and the adjusted ELV will be calculated. Since the costs of a possible revision are estimated assuming full implementation of the POP Protocol and full implementation of autonomous measures, the costs in the EU25 will appear lower than for other countries because the EU25 countries have to comply with EC Directives and already made or will make (a part of) the costs. The costs will be presented as total annual costs (the sum of amortization and operational costs) and are expressed in Euro (€) as of year 2000. However, a clear year of reference for costs of specific measures is often not given and costs have to be seen as a good approximation but not the absolute truth – this is further detailed in the next paragraph. When calculating the costs per tonne of emission prevented (not-emitted) all costs for a specific measure will be taken into account despite the fact that a measure may generate emission reduction for other substances as well. This is a necessity because it is at present not possible to weigh e.g. a PCDD/F emission reduction as compared to e.g. emission reduction of a heavy metal or other POP. However, because the co-benefits of the measures are not accounted for in the costs, one may argue that the costs are overestimated.

3.1 Limitations of the cost data used

A general observation from the literature as well as annexes to the UNECE Protocols is that – if available at all - the indicated investment and cost figures are often highly case-specific and depend on such factors as plant capacity, removal efficiency and raw gas concentration, type of technology, and the choice of new installations as opposed to retrofitting. For example, Rentz et al (2004) collected data on costs of abatement measures for heavy metal emission reduction as a preparation of the revision of the HM Protocol. Rentz et al (2004) explicitly note that the new cost data may not be comparable with the existing information in Annex III of the HM Protocol. Moreover, they state that it is very difficult to give reliable cost data which could be used in a more general sense without the danger of misleading results and conclude that an accurate comparison of cost data is, in general, not possible (Rentz et al, 2004). The reasons for incomparability and difficulties listed by Rentz et al. (2004) that complicate obtaining reliable general applicable cost data are also applicable to POP reduction investment and cost figures, especially for the emissions due to unintentional releases. Thus it can be concluded that the costs of emission reduction as indicated in this study gives an order of magnitude of the cost range for a specific technology. It allows only a limited comparison of costs between techniques and countries.

3.2 Possible measures to further reduce POP emissions from stationary sources and their associated costs

In the earlier phase I study Denier van der Gon et al. (2005) estimated the effect of implementation of BAT for major stationary sources of POP as a result of the UNECE POP Protocol. An assessment of the remaining sector contributions is discussed in chapter 2.

3.2.1 Electric Arc Furnaces

Electric arc furnaces (EAFs) are identified as a candidate source for a further revision of the POP Protocol based on a key source analysis (Table 5, chapter 2). EAFs are one of the remaining sources of PCDD/F, with a residual contribution of ~17%. The preliminary conclusion drawn in Phase I (Denier van der Gon et al., 2005) was that the implementation of BAT may not be enough to optimally reduce the PCDD/F emissions of EAFs and that additional measures may be proposed. The emission limit value (ELV) chosen in the present study for electric arc furnaces is 0.5 ng Teg/m^3. In 2005 Canada submitted a review and summary of existing ELVs for PCDD/F, to the Task Force (TF) on POPs (UNECE, 2005a). According to this review, existing ELVs for EAF range from 0.1 to 5 ng Teq/m^3 where 0.5 can be regarded as a realistic value which does not pursue maximum possibilities but is well within the range of the review. Furthermore, at the same Task Force meeting in Rome the USA submitted a Review of Best Available Techniques to Control Emissions of POPS from Major Stationary Sources (UNECE, 2005b). This work suggests a range of 0.01 to 0.5 ng Teq/m^3 for what could be achieved by implementation of BAT. The value (0.5) selected in this study equals the upper boundary of the range in the BAT review (UNECE, 2005b).

According to Annex V of the Protocol the combination of a fabric filter and the injection of activated carbon is considered BAT for EAFs. We can identify the addition of a scrubbing system as a means to reduce PCDD/F emission further. Addition of a flue gas scrubber would bring the technical level of the emission control on par with e.g. the incineration of municipal solid waste. Entec (2001) specifies costs of emission control equipment of this type, for incineration processes. The total annualised costs for a scrubber amounts to 1.3 M€ for a 300 ktonnes/year MSW incinerator that we can increase with a factor of 1.3 (Berdowski et al., 1998) to account for higher costs of retrofitting.
300 ktonnes/year would result in a flue gas flow rate of approximately 250000 Nm^3/h (assuming 6700 Nm^3/tonne waste). The specific waste gas production of an EAF is in the order of 5000 – 20000 (12500) Nm^3/tonne steel and the average EAF has a capacity of 500 ktonnes/yr (Denier van der Gon et al., 2005), which is 62.5 t/h. Hence, the hourly gas flow rate would be 780000 Nm^3/h for an average EAF. Compared to an incinerator, the specific scrubber capacity (capacity per tonne production capacity) has to be 12500 / 6700 = 1.87 times

higher for an EAF. Assuming a linear relation between costs and flue gas flow rate, total annual costs for a 500 ktonnes/year EAF can be estimated at 4 M€, which is *8 € per year per tonne installed capacity.*

However, whether EAFs are truly a good candidate for revision of the POP Protocol warrants further study. Denier van der Gon et al. (2005) estimated the effect of implementation of BAT based on information from Annex V that includes guide numbers for emission strengths before and after implementation of BAT. An emission reduction factor was derived from this data and applied, in order to estimate the emission reduction. This approach demonstrated with a reasonable degree of confidence how the implementation of BAT would reduce the contribution of the majority of sectors to POP emissions. However, for EAFs no conclusive estimate for the effect of BAT could be made as the reported PCDD/F concentrations before and after BAT appeared to be of the same order. Therefore, the estimated residual contribution for PCDD/F by EAFs of 17%, (as derived by Denier van der Gon et al., (2005) and presented in Table 5) needs to be verified by a bottom-up estimate. For example, the background documentation in Annex V reports lowest PCDD/F emission with BAT to be about 0.1 ng Teq/Nm^3. Assuming a specific waste gas generation of 12500 Nm^3/tonne this leads to an emission factor of 1.25 µg Teq / tonne. The total production of secondary steel in 2020 is projected to be 116 tonnes, suggesting a contribution of only 4% (146 g) instead of 17% (652 g). Hence, the reported 17% contribution EAFs to PCDD/F emissions could potentially be an overestimation. So, before final action would be taken to include EAFs in a revised Protocol, it is highly recommended to do a more in depth assessment focussing on emissions of EAFs in UNECE Europe. It should be noted that the use of TNO reference (default) emission factors in Denier van der Gon et al. (2005) was to fill gaps in the official submitted data and a in-depth review of emission factors was beyond the scope of the study. However, it is also possible that the official submitted data dominate the estimate of PCDD/F emissions from EAF and these may be based on accurate local/national knowledge. So, the above remarks should not be interpreted as a disqualification of the 17% contribution of EAFs tot remaining PCDD/F emissions but as a cautionary remark. Again, to increase confidence a comparison between official emission data, expert emissions and a review of emission factors is needed but out side the scope of the present study.

3.2.2 Incineration of non-hazardous industrial waste

A significant contribution to the projected PCDD/F emissions for 2020 assuming full implementation of the current POP Protocol is made by the incineration of non-hazardous industrial waste. This activity is not specifically addressed by the current Protocol and therefore no stringent ELV can be applied when estimating emission assuming full implementation of the POP Protocol. The result is relatively high emissions in the projected emission inventory because other sources have been significantly reduced. Depending on the existing degree of emission reduction, 5 different technology classes are distinguished in the TNO reference database. The PCDD/F emission factors used for the incineration of industrial waste are 0.5, 10, 30, 350 and 3500 µg Teq/tonne. These factors roughly correspond with 'large highly controlled plants', 'large units equipped with ESP only', 'large uncontrolled plants' and 'small uncontrolled plants' and respectively refer to 5 country groups (Table 8). The measures needed to comply with an ELV are reckoned to be similar to those for other incineration processes (e.g. municipal waste). Table 8 specifies the existing control equipment for 5 country groups, the emission factor used in the TNO reference database and the additional measures that would be needed to meet an ELV of 0.5 ng Teq/m^3. The cost data presented in Table 8 have been taken from (ENTEC, 2001).

Table 8 Country grouping of waste incinerator plants, respective PCDD/F emission factors, possible measures to reduce PCDD/F emissions and their associated costs.

Group	**Description of plant as existing**	**PCDD/F Emission factor (µg Teq/tonne)**	**Proposed Measures**	***Total annual specific costs (€ per tonne capacity / yr)***
1	Highly controlled, scrubber, coal injection	0.5	None	0
2	Large unit, ESP only	10	Scrubber, carbon injection, bag filter	8.5
3	Large unit, ESP only	30	Scrubber, carbon injection, bag filter	8.5
4	Large uncontrolled	350	ESP, scrubber, carbon injection, bag filter	10
5	Small uncontrolled	3500	ESP, scrubber, carbon injection, bag filter	20[a)]

a) Specific cost of measures for Group 5 are estimated to be at least twice as high as for group 4 due to scaling effects (Berdowski et al., 1998).

3.2.3 HCB emissions from the secondary aluminium industry

One of the main metal treatment operations that may be carried out in aluminium melting processes is degassing. This involves the removal of hydrogen gas from the melt, traditionally by the addition of solid degassing agents, for example hexachloroethane. The use of hexachloroethane (HCE) in aluminum foundries and remelting plants to remove hydrogen gas bubbles from molten aluminum yields a number of organochlorine compounds, most notably HCB. This source of HCB is not explicitly addressed in the 1998 POP Protocol. However, due to effectively abating other HCB emission sources it is an important remaining source of HCB emissions. There is an apparent trend to move away from HCE usage in secondary aluminum operations, encouraged by policy initiatives such as PARCOM Decision 96/1 on the Phasing-Out of the Use of Hexachloroethane in the Non-Ferrous Metal

Industry. Other degassing systems exist and are capable of attaining similar or even superior technical efficiency and performance with alternative substances involving less ecological risk. Alternative degassing agents include argon or nitrogen (chlorine gas being a less attractive substitute). According to information in the Technical Annex of the POP Protocol, costs associated with abandoning the use of HCE are low. The switch from HCE to alternatives has for a significant part taken place already and reportedly without too much difficulty.

We therefore assume that the elimination of hexachloroethane (HCE) as degassing agent in the secondary aluminium industry is mostly cost-neutral. We furthermore assume an average of 90% HCB emission reduction as a result of elimination of HCE as degassing agent.

3.2.4 Controlling hexachlorobutadiene (HCBD) emission in the production of primary magnesium

Primary magnesium can be produced in two ways depending on the type of available raw material: a thermal or an electrochemical process, the latter finding the most application. The electrochemical process involves the chlorination of raw MgO in a chlorination furnace, followed by electrolysis where molten $MgCl_2$ is reduced to Mg and Cl_2. In both steps (but especially in the chlorination furnace) chlorinated hydrocarbons including HCBE are formed as unwanted by-products in small but significant quantities. This source is not explicitly addressed in the 1998 POP Protocol as HCBD is not (yet) included in the Protocol.

According to (IPPC, 2001) waste gasses from magnesium production are as a rule collected and cleaned by wet scrubbers, wet ESP, afterburner and bagfilters. Reported average volumetric capacities of the used incinerators (afterburners) are in the order of 70,000 Nm^3/h for a 30,000 tonnes/year plant. The flow through the afterburner is the most relevant HCDB laden gas stream in the process. Further reduction of chlorinated hydrocarbon emission can be achieved by injection of activated carbon (IPPC, 2001). We estimate that existing plants are all equipped with above mentioned control technologies, except the injection of activated carbon. Secondly, we estimate that (based on information from the BREF documents) an additional reduction of organochlorines of 95% is achieved with the injection of activated carbon.

On the basis of the cost information available for power plants (Visschedijk et al., 2006), a rough additional estimate of the costs for HCDB removal has been made based on a specific waste gas production of 20,000 Nm^3/tonne magnesium:

Investment costs € 90 / tonne production capacity (in tonnes/year)
Operational costs € 20 / tonne production capacity (in tonnes/year) · year^{-1}

3.3 Possible measures to reduce emissions of POP and/or substances possibly proposed to be added to the POP Protocol from product use and their associated costs

3.3.1 Lindane

Denier van der Gon et al. (2005) estimated the total use of Lindane (gamma-HCH) in Europe for the year 2000 at around 250 tonnes. The UNECE POP Protocol restricts the use of Lindane to:

- Seed treatment
- Soil applications directly followed by incorporation into the topsoil surface layer
- Professional remedial and industrial treatment of lumber, timer and logs
- Public health and veterinary topical insecticide
- Non-aerial application to tree seedlings, small-scale lawn use, and indoor and outdoor use for nursery stock and ornamentals
- Indoor industrial and residential applications

According to Denier van der Gon et al. (2005) the only substantial uses in 2000 (and presumably in 2010/2020) are seed treatment, soil incorporation and industrial wood preservation. The restricted uses are scheduled to be re-evaluated under the Protocol two years after the date of entry into force. Lindane is also likely to be withdrawn from the EU(25) market by the year 2008 under the Agricultural Pesticides Directive 91/414/EEC.

The OSPAR Background Document on Lindane (OSPAR, 2004a) and the UNECE Dossier on Lindane (UNECE, 2004) list alternatives for the use of Lindane in various applications. Lindane is relatively cheap, stable and is active against a broad range of insects. Replacements for Lindane might not possess all these properties to the same extent. But experience has shown that it is certainly feasible to replace Lindane without too much difficulty.

3.3.1.1 Industrial wood preservation

For industrial (large scale) wood preservation, several organic and anorganic substances are recommended by (OSPAR, 2004a) for the preservation of wood, including azaconazole, boric acid, chromic acid, Cu/Cr/As salts and sodium fluoride. For insecticidal use specifically, products containing deltamethrin, chlorpyrifos and permethrin would be similarly effective and are normally applied in the same manner as Lindane (spraying). Based on literature data (Hall and Halloway, 1996; IFCS, 1996; Georghiou, 1986) we estimate the specific cost (cost per application unit) of Deltametrin to be about 3 times higher than that of Lindane.

The cost of Lindane is approximately $10/kg A.I. (Georghiou, 1986), which leads to specific replacement costs of *$20 (= €16) /kg Lindane*.

3.3.1.2 Seed treatment

Lindane is also used as broad spectrum insecticide and acaricide for the treatment of agricultural seed. Conventional alternatives for Lindane in this application are organophosphates, permethrin and pyrethrins (OSPAR, 2004a; UNECE 2004). More modern replacement products for Lindane comprise insecticides in the neonicotinoid class. The specific costs of Lindane containing products such as Germate, Kernel Guard, Sorghum Guard or Grain Guard Plus are mostly in the order of $2 – 8 (average of $4) / 100 lbs seed, according to various literature data. The specific cost of the neonicotinoid imidacloprid would be around $10 / 100 lbs seed (e.g. for the product Gaucho 480) for standard dosage. Hence, we can estimate the additional costs of replacing Lindane for seed treatment applications to be *€12 /kg Lindane*. At this stage it is not clear what part of the reported Lindane usage in agriculture is used for seed treatment and what part for soil incorporation. Both applications are frequently mentioned as being important but the official usage data only refer to the sum of agricultural use. We assume therefore a 50/50 distribution.

3.3.1.3 Soil disinfection

One of the main applications of Lindane that is still allowed by the POP Protocol is soil incorporation. Lindane is used against soil insects and is to be applied in a way that volatization is avoided. Soil incorporation takes place once a year before any crop is planted. We therefore assume that replacing Lindane with a different (and probably less persistent) substance will not necessitate an increase in application frequency. Possible changes in crop yield have been disregarded, in spite of a possible decrease of residual insecticidal activity. When only considering the price of the alternative pesticide, the specific cost of replacing Lindane can be estimated by comparing specific costs of Lindane and the replacement. A frequently mentioned and equally effective replacement for Lindane would be the neonicotinoid imidacloprid. The product Gaucho 480 contains imidacloprid as active ingredient. Specific costs range from $10 to $30 per acre (Borges and Gaska, 2004), compared to $1 to $5 for Lindane. Taking 1 US$ to be ~0.8 €, the estimated replacement costs are *€56 / kg Lindane* for this application.

3.3.2 Endosulfan

Total annual consumption of Endosulfan in UNECE Europe is estimated to be 1550 tonnes (Denier van der Gon et al., 2005). Usage in the former EU(15) was derived from sales data by Aventis Crop Science and consumption in the other

UNECE Member States was estimated to be 1.7% of the total insecticide consumption. The substance is used as an insecticide and acaricide on hops, rape, vine, soft fruits and ornamentals. Further usage is reported for soil and seed disinfection and application in forestry. In Europe its primary use is in vine yards and soil and seed spraying (OSPAR, 2004c).

For most applications of Endosulfan alternatives are available (UBA, 2004). Among existing substitutes are organophosphorous pesticides like methamidiphos, phosphomidon, dimethoate and profenophos, organo-thiophosphates like oxydemethon-methyl, or pyrethroids, e.g. (beta) cyfluthrin and fenpropatrin (UBA, 2004; OSPAR, 2004c). Examples of the specific costs of Endosulfan versus various alternative insecticides are shown in Table 9. Costs in Table 9 only account for pesticide costs, labour and equipment costs are disregarded.

Table 9 Examples of specific costs of Endosulfan compared to various alternatives.

Class / Active ingredient	**Product name**	**Price**	**Unit**	**Specific cost**	**Range**
		(US$)		**(€ ha^{-1})[b]**	
Endosulfan:	Thiodan 4EC [a]	15	$/L	30	8-47
	Endosulfan 400 [a]	14	$/L	28	12-20
	Endosulfan 50W	14	$/kg	16	9-52
Organophosphorous pesticides:					
Methamidiphos	Monitor	15	$/L	18	7-28
Dimethoate	Dimethoate 480	23	$/L	14	5-22
	Dimethoate	15	$/Gal	10	
	Cygon 480	23	$/L	14	5-22
	Cygon 4E	26	$/L	16	6-25
Organo-thiophosphates:					
Oxydemethon-methyl	Metasystox-R	64	$/Gal	20	
Pyrethroids:					
Cyfluthrin	Baythroid 2E	361	$/Gal	12	9-16

[a] A.I. content 400g/L

[b] Recalculated using 1 acre = 4047 m^2; 1 Gal = 3.785 L; 1 US$ = 0.8 €

Sources: Alberta Government (2006), OSPAR (2004c), UBA (2004), Mulder and Seuhs (2003), ERS AAFC (1999), NASS USDA (1998)

Endosulfan appears not to be a particularly cheap pesticide when only regarding the product’s retail price and costs per area (Table 9). In fact, the suggested substitutes are in most cases even cheaper. It is however important to realize that within the present study it is not feasible to assess possible changes in product yield and/or quality, which would, if present be an important aspect of the costs of elimination of Endosulfan.

Moreover, various experts are of the opinion that endosulfan can not be entirely phased out as it would remain vital to insecticide resistance management strategies (offering a control option from a distinctly different chemical class), as well as to control certain pests for which no equally effective alternative is available (UBA, 2004). Whether and to what extent this is actually the case would have to be determined by a specific study that is beyond the scope of the present study. Therefore, we will assume that the bulk of the present use of Endosulfan can be substituted.

One of the reported advantages of endosulfan is that it often offers a one-shot control of various, difficult to control pests. For many pests the substance has a strong residual effect, partly due to its persistence. It is possible that if endosulfan was to be replaced with a more rapidly degrading alternative, the application frequency would need to increase (Berdowski et al., 1997; UBA, 2004). This is potentially cost-raising not only because product costs but especially because of additional labour costs involved. Berdowski et al. (1997) estimate the costs per insecticide application round by spraying at €50 – 200/ha, depending on the (local) labour costs. This estimate takes into account labour as well as rental and/or amortisation costs of equipment and costs of solvents, but again no yield effects. A rough first order estimate of the increase in application frequency is a factor of 2 (Berdowski et al., 1997), which would lead to replacement costs of €50 – 200/kg Endosulfan when assuming an average dosage of 1 kg A.I./ha. This would have to be increased with the costs of the alternative pesticide itself (~€20; Table 9).

Potential cost of Endosulfan replacement is estimated at about €70 – 220/kg.

As indicated earlier, the range in replacement costs originates from differences in labour costs in UNECE-Europe. In the cost of replacement calculations this has been explicitly taken into account by using country-specific agricultural labour costs obtained from Eurostat (2006). An increase in pesticide application frequency as a result of replacing Endosulfan is deemed realistic but it is not an established fact. Furthermore, the projected Endosufan consumption in 2010 and 2020 is also rather uncertain, given the more or less conflicting usage trends observed in Northern and Southern Europe during the 1990ties (OSPAR, 2004c) and the lacking information concerning national policies. Thus the above estimated replacement costs are best to be considered as the upper boundary of the range in actual costs. The lower end of the range would be the cost of the replacement pesticide only (estimated at €20/ha, Table 9).

An alternative to chemical control of insects is biological control (e.g. as part of Integrated Pest Management (IPM) programmes), which shows promising results and a steady increase in popularity in recent years. IPM programmes include phyto-sanitary and cultural measures supplemented with bio control measures and mass trapping of insects. At this moment cost is the principal constraint on the use of biological control and many methods are still under development. For this alternative to Endosulfan it is too early to conclude which pests can be effectively controlled and at what cost. Several studies (e.g. Van Driesche et al., 2002) show that the difference in cost between chemical and biological control is declining and that in specific cases bio control is even cheaper, making it a valid alternative to the use of agrochemicals.

The elimination or restriction of the use of Endosulfan that might be incorporated in the POP Protocol could be accompanied by a ban on marketing and producing the substance as well. This could result in a financial loss for pesticide producers and possibly traders as well. For a large part this could be compensated by the production and trade of alternatives but it is difficult to predict to what degree. In Europe there is one manufacturer that produces Endosulfan at a rate of 4,000 tonnes annually. When we estimate the profit margin of the wholesale and retail combined at about 30 – 40%, the ex-factory sale price would be about 20€/kg A.I., resulting in a producer’s turnover of 80 M€. According to information by the Australian PSA (PSA, 1993) the manufacturers profit margin lies between 5 to 10% which would mean 4 to 8 M€ in this case.

3.3.3 Dicofol

Dicofol is an organochlorine insecticide/acaricide that was introduced as an alternative to DDT. Among its main applications in Europe nowadays is the use as a miticide on grapes and lemon (Haskoning, 2003). In Europe Dicofol is produced by Rohm & Haas in a quantity of 1,500 tonnes annually and marketed under the product name Kelthane. Denier van der Gon et al. (2005) estimated the total Dicofol consumption in Europe in the year 2000 at 320 tonnes. This estimate is based on usage data by OSPAR (2004b) and Haskoning (2003; 2005). The consumption by countries that were not covered by the OSPAR or Haskoning studies is estimated based on the total areas of grapes and lemon, and specific dicofol consumption derived from known usage data.

The literature suggests many possible alternatives to Dicofol, the most frequently being organophosphorus insecticides such as dimethoate and ethion, acarides including abamectin, triarathene (diflubenzuron), fenbutatin-oxide, propargite and clofentezine, and pyrethroids with also some acaricidal activity such as fenpropathrin. However, which substance is the most viable substitute for Dicofol is very dependant on the type of pest to be controlled. The price of Dicofol and alternatives for Dicofol is compared in Table 10. Table 10 only accounts for pesticide costs, labour and equipment costs are not taken into account.

Table 10 Examples of specific costs of Dicofol compared to various alternatives.

Class / Active ingredient	Product name	Price	Unit	Specific cost	Range
		(US$)		(€ ha^{-1})a)	
Dicofol	Kelthane 35WP	10.20	$/lb	20	10-79
	Kelthane MF (40.7% W)	13.00	$/lb A.I.	14	8-20
Acaricides:					
Abamectin	Agri-Mek 0.15 EC	608.90	$/Gal	99	40-198
Triarathene (diflubenzuron)	Micromite 25WP	30.44	$/lb	79	
Fenbutatin-oxide	Vendex 50W	15.68	$/lb	40	30-59
Propargite	Omite 30WP	6.49	$/lb	59	
Clofentezine	Comite 6.55 EC	83.39	$/Gal	30	16-59
Organophosphorus insecticides:					
Dimethoate	Cygon 480	10.00	$/L	14	5-22
	Cygon 4E	4.00	$/L	16	6-25
	Dimethoate	36.40	$/Gal	10	
Ethion	Ethion 8 EC	34.34	$/Gal	8	
Pyrethroid insecticides:					
Fenpropathrin	Danitol 2.4 EC	157.00	$/Gal	32	13-51

a) Recalculated using 1 acre = 4047 m^2; 1 Gal = 3.785 L; 1 US$ = 0.8 €

Main source: Muraro et al. (2002); Specific use per unit of area is based on manufacturer's specifications

The data in Table 10 suggest that classic organophosphorus insecticides such as dimethoate and ethion may be marginally cheaper than Dicofol when used in the same frequency. However, organophosporus substances might not always be as effective as acaricides. There is a number of specific acaricides that are at least as effective as Dicofol for many pests but these are significantly more expensive, with costs sometimes topping $100,-/acre (~200 €/ha). On average, alternative acaricides are about three times more costly per unit of area treated. It is important to realize that possible changes in crop yield and/or quality have not been taken into account which would, if present, be an important aspect of the replacement costs. For example, the US EPA reports possible ranges of 3 to 30% decrease in yield in this respect.

Dicofol is usually applied once per growing season. Resistance to Dicofol and its alternatives is frequent. There is in fact a shortage of effective miticides at this moment, perhaps explaining the high substance costs of many acaricides. Dicofol is traditionally produced from DDT, that might also still be present as impurities. The risk of contamination by DDT therefore exists.

The persistence of Dicofol reveals itself in a strong residual effect. When Dicofol would be replaced by another substance an increase in application frequency is considered to be a possibility. Berdowski et al. (1997) estimated the labour costs per insecticide application round by spraying at €50 – 200/ha, depending on the (local) labour costs. Specific cost of an alternative to Dicofol would be €60/ha and specific costs of Dicofol are 17€/ha (Table 10). To estimate the replacement cost including labour cost of an additional application, we take the labour cost once, the cost of the alternative twice and then subtract the cost of the replaced Dicofol to get the total specific replacement costs, amounting to €100-325/ha. This figure can be considered an upper boundary of the Dicofol replacement costs. The lower boundary represents the incremental cost of the substitute pesticide only, which is ~45€/ha. Furthermore, 1 kg Dicofol is equivalent to 2 ha of area treated, assuming an average dosage of 0.5 kg Dicofol/ha (OSPAR, 2004b).

Costs per unit of Dicofol equivalent range from €90 to €215 – 665/kg Dicofol replaced.

As indicated earlier, the range in the upper range (€215 – 665/kg) of replacement costs originates from differences in labour costs in UNECE-Europe. In the cost of replacement calculations this has been explicitly taken into account by using country-specific agricultural labour costs obtained from Eurostat (2006). Clearly alternatives that would not require an additional application round should be preferred as the costs are substantially lower (€90 as compared to €215 – 665/kg).

Similar to Endosulfan, an alternative to chemical control only is Integrated Pest Management (IPM). IPM involves a sophisticated combination of biological, agricultural, and chemical control for a specific pest. IPM usually results in a lower consumption of chemicals and is recommended in the literature in order to reduce pesticide consumption. It is beyond the scope of this study to devise an IPM strategy to every potential Dicofol use but it is important that IPM is mentioned in this respect.

3.3.4 Pentachlorophenol (PCP)

Pentachlorophenol is used mainly as a fungicide. Its salt, sodium pentachlorophenate (NaPCP) is used for similar purposes and readily degrades to PCP. The ester, pentachlorophenyl laurate (PCPL), is also used. All three substances are toxic, persistent and liable to bioaccumulate, although PCPL is less toxic by an order of magnitude (OSPAR, 2001a). The major uses of PCP in UNECE Europe are sap stain control and wood preservative. For more details we refer to OSPAR (2001a), Borysiewicz and Kolsut, (2002) and Denier van der Gon et al. (2005).

3.3.4.1 Further reduction of PCP emissions

The proposed measure to reduce PCP emissions in UNECE-Europe is a total ban on the use of PCP and its salts and esters. The use of substances and preparations to which PCP and its salts and esters have been added intentionally is banned in the EU since 2000 through Commission Directive 1999/51/EC. Only the oceanic maritime Member States (France, Ireland, Portugal, Spain and the United Kingdom), were permitted to choose not to apply the total ban until Dec. 31, 2008. These states were allowed to abide by the 1991 restrictions (with the amount of allowable dioxin impurities further reduced from the 1991 Directive) because it was deemed that certain uses of PCP are still necessary for technical reasons. As this derogation will end in 2009 we assume that in 2010 throughout the EU the use of PCP will be banned due to autonomous measures. It is assumed that this ban will be implemented throughout the EU25+ as of 2010. In Phase I of this project (Denier van der Gon et al., 2005), the autonomous measures described above (involving an elimination of PCP in the EU(25)+ by 2020) were not accounted for. This results in a European 2020 emission equalling the 2000 value. When we would include the described autonomous measures, the European emission total would drop for 705 to 302 tonnes as a result (see 3.3.4.3). Therefore, no additional costs due to a possible ban on PCP are expected in the EU(25)+, as the costs (if any) will be made as the result of autonomous policies.

3.3.4.2 Alternatives for PCP and associated costs

The major uses of PCP in UNECE-Europe are sap stain control and wood preservative. In general, a number of alternatives to the use of PCP or PCP treated products are available, such as untreated wood, alternatively treated wood, stone, brick, steel, materials made from recycled plastics, cement board panels, concrete blocks, and concrete.

The major proportion of sawn timber produced in Europe is subject to sapstain and mould growth. For the production of high quality timber this loss of aesthetic qualities is an obvious problem. However, within Europe the problem of mould and stain on lower priced package and pallet board timber currently presents an even greater problem. The sap stain control can be replaced by kiln drying of the freshly cut timber as is commonly done in the Nordic countries. In countries such as Sweden producing high quality building and furniture, timber kiln drying has expanded considerably with around 80% of current production dried this way. Although kiln drying can prevent fungal growth, re-wetting during transport and storage and subsequent fungal development remains a problem. Wrapping of packs to prevent wetting from rain can also cause condensation making chemical protection a necessity. So, a form of chemical treatment is still the norm to prevent stain due to this accidental wetting. Moreover, kiln drying of wood for pallet production and box timber would prove prohibitively expensive and lead to rejection of much of the timber in a market where size and distortion tolerances are critical due to automatic production of many of the final products (AIR2-CT93-1059, 2006). In the recent past the industry worldwide has relied almost exclusively on the use of Sodium Penta chlorophenoxide (NaPCP) for sapstain control. This chemical is highly effective and very forgiving of bad application and

poor quality control at the saw mills. Various chemical alternatives to PCP for wood preservation have been developed e.g. arsenic preparations (chromated copper arsenate – CCA), Zinc naphtenate (available in preparations with organic solvents as well in water soluble preparations), Copper-8-quinolinolate, Copper Naphthenate. (Borysiewicz and Kolsut, 2002; Nicholas and Freeman, 2000; AIR2-CT93-1059, 2006).
The list of replacements and alternatives for PCP is large, ranging from use of other (non-PCP treated) materials to chemical substances to replace the PCP. Many countries have succeeded in banning the use of PCP years or sometimes decades ago and within the EU its use is banned as the result of autonomous measures. Therefore it is assumed that no additional costs due to a revision of the UNECE POP Protocol are involved in banning the use of PCP but the major challenge to wood producers is selecting the right alternative that is the most cost-efficient replacement.

3.3.4.3 Future emissions of PCP

A ban of PCP use will not immediately result in zero emissions of the substance because emission will continue from in-use products. The estimated average life time of treated wood is 15 years (crates: 5 years, fences: 10 years and construction wood: 30 years).
For 2000 it was assumed that France, Portugal, Spain and the United Kingdom and all countries outside the former EU(15) still used PCP, whereas the other countries within the former EU(15) abandoned PCP use earlier. However, all countries in the EU(25)+ are expected to stop using PCP by 2010. Hence, fresh usage will only occur outside the EU(25)+ in 2020, however emission from in-use PCP treated wood would may still occur France, Portugal, Spain, United Kingdom and all non-EU(15) countries. The UNECE 2020 emission after autonomous measures and full implementation of the 1998 POP Protocol is estimated at 302 tonnes (instead of 705 tonnes that is mentioned in Denier van der Gon et al. (2005)). This figure includes PCP released as an unwanted by-product.

This estimate is among others based on a simple methodology described in Denier van der Gon et al. (2005) that comprised comparing known PCP usage data with total fungicide consumption as reported by FAO, in order to come up with a representative value for the PCP fraction. In case no country data were available PCP usage was estimated as 0.44% of the fungicide consumption for that particular country as reported by FAO. Furthermore, the emission of treated wood in the former EU(15) countries that banned the use of PCP in 2000 or before will be negligible by 2020 as the average service life of treated wood is 15 years.

A possible revision of the POP Protocol according to the measures proposed in this study involves a complete elimination of PCP usage by 2010. This implies that there is no fresh use in 2020 anywhere in UNECE Europe and limited residual emission from existing PCP treated wood in France, Portugal, Spain, United Kingdom and all non-EU(25) countries. The residual emission is estimated as follows: Emission in 2020 is 0.0044 * Total usage of Fungicides by FAO * 5 (years). Note that if a country has officially reported emissions, this figure will overwrite the estimated emission using the TNO default methodology. Thus we estimate that the total PCP emission after possible revision of the Protocol would be 207 tonnes. This figure again includes the PCP that is released as an unwanted by-product.

3.3.5 Pentabromobiphenyl (PeBDE)

Pentabromobiphenyl (PeBDE) falls under the group of brominated flame retardants. Brominated flame retardants are known to be toxic, were given priority in the 1992 OSPAR Action Plan, and therefore included in 1998 in the List of Chemicals for Priority Action. The polybrominated diphenyl ethers (PBDEs) are a group of aromatic brominated compounds formed by substituting bromine atoms for hydrogen atoms in diphenyl oxide. The bromine content can vary between two and ten atoms. PBDEs are in thousands of everyday products, including electronics equipment, lighting, wiring, building materials, textiles, furniture and industrial paints. These fire retardants often make up a considerable proportion of product weight: Plastic can be up to 15 percent PBDEs and polyurethane foam up to 30 percent PBDEs (WHO, 1994; ECB, 2001; 2003). Three different PBDE flame retardants are commercially available. They are referred to as penta-BDE (PeBDE, 5 bromine atoms), octa-BDE (8 bromine atoms) and deca-BDE (10 bromine atoms).

- DecaBDE is a general purpose additive flame retardant for a range of plastics including PE (polyethylene), PP (polypropylene), PBT (polybutylene terephthalate), UPE (unsaturated polyesters) and PA (polyamide, nylon).
- OctaBDE is primarily added as a flame retardant to ABS (acrylonitrile butadiene styrene) polymers at 12-18% by weight (ECB, 2003). ABS is the most common plastic in electrical and electronic equipment produced in Europe. In 2005 the European Union has submitted a dossier to UNECE TFPOP to nominate OctaBDE for inclusion into Annex 1 of the Protocol to the Convention on Long-range Transboundary Air Pollution (LRTAP) on Persistent Organic Pollutants (EC, 2005b). However, at the time of conception and definition of the present study (2003) this was not yet known. Some additional information on octaBDE is summarized here but the substance is not further addressed in this study. OctaBDE) is a mixture of several polybrominated diphenyl ethers. In Europe, OctaBDE is banned under the 24th amendment to the marketing and use Directive 76/769/EEC since 15 August 2004. As a result of declining demand, the sole US manufacturer of this product voluntarily ceased production in 2004. There is presently no known commercial production of this substance remaining in the US and Europe. The fact that commercial octaBDE consists of several polybrominated

diphenylethers and congeners, makes the assessment of POP characteristics difficult. Overall, the EC (2005b) suggests that octaBDE congeners fulfil the criteria of the Decision 1998/2 of the UNECE Executive Body for persistence, potential to cause adverse effects and potential for long range atmospheric transport, whereas the situation with criteria concerning bioaccumulation is less clear. However, it is important to note that commercial octaBDE contains significant amounts of at least two component groups (penta- and hexabromodiphenyl ethers) that appear to meet all the criteria for POPs. Therefore, according to EC (2005b) it can be concluded that commercial octaBDE meets the UNECE screening criteria. An additional concern is the possible formation of brominated dibenzo-p-dioxins and dibenzofurans during combustion and other high temperature processes involving articles treated with octaBDE flame retardants (EC, 2005b).

- PentaBDE is used as an additive flame retardant mainly in flexible polyurethane foams (PUR). PeBDE is toxic and may disrupt the oestrogenic system (e.g. OSPAR, 2001b; EPA, 2005). In this study as well as in the previous emission inventory (Denier van der Gon et al., 2005) only emissions of PeBDE are addressed.

3.3.5.1 Usage of PeBDE

Around 95% of penta-BDE used in the EU is used as an additive flame retardant in flexible polyurethane foam used for mattresses, car seats, foam-based packaging and polyurethane elastomer instrument casings (ECB, 2001). The penta-BDE is added in concentrations of 5-30% by weight.
The use of PBDEs is rapidly changing due to various policies to reduce or ban the usage and dispersion in the environment. European commission Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) provides “that from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, PBB or PBDE.” California is the first U.S. state to take action, passing a law to ban certain PBDEs in 2008. Most likely several other states will follow and the major producers of PBDEs are considering and/or already implementing voluntary phase out of the production.

3.3.5.2 Alternatives for PeBDE and associated costs

Brominated flame retardants only account for about 15% of the global flame retardant consumption. Consequently a large number of compounds may be considered as alternatives (OSPAR, 2001b). Substitution can take place at three levels:

- Brominated flame retardants can in some applications be replaced by another flame retardant without changing the base polymer;

- The plastic material, i.e. the base polymer containing flame retardants and other additives, can be replaced by another plastic material;
- A different product can replace the product, e.g. the plastic material is replaced by another material, or the function can be fulfilled by the use of a totally different solution.

PeBDE (as well as the other PBDEs) are the most widely used in North America (BSEF, 2000). Leading U.S. flame-retardant chemical manufacturers identified 14 chemical formulations that are potentially viable substitutes for pentaBDE in large-scale production of low-density flexible polyurethane foam. EPA assessed the hazards, potential exposures and tendency to bioaccumulate and persist in the environment for the chemicals in each formulation (EPA, 2005). Penta-BDE alternatives include chlorinated phosphoric acid esters, organic triaryl- and bisphosphates, ammonium polyphosphate, melamine, or reactive phosphorus polyols. According to Lassen et al., (1999) and Leisewitz et al. (2001) prices for the alternatives are approximately the same. Alternatives are readily available and have been applied for many years. This not to say that replacement of PeBDE will be without obstacles in all cases. Formulations of several alternative chemicals are available only as solids; making them less desirable as drop in substitutes for PeBDE. Since the commercial mixture PeBDE is liquid, addition of a solid flame retardant may require changes such as additional mixing steps and alteration of the process times. In some cases, these changes can have significant effects on foam quality or cost-effectiveness of manufacture. However, again in such cases the manufacturer may have other options such as non-chemical alternatives. For example, three currently available, alternative technologies for flame retarding furniture include barrier technologies, graphite impregnated foam and surface treatment.

Replacing PeBDE may indeed challenge the creativity of foam manufacturers but as a general principle it is concluded that for this particular flame retardant alternatives are available at approximately the same costs. Hence a ban on the use of PeBDE is assumed to be cost-neutral.

Recently, an overview of “Management Options for commercial PeBDE” was submitted to the fifth meeting of the LRTAP Task Force on Persistent Organic Pollutants (TFPOP), Tallinn, 29 May-1 June 2006..The cost implications outlined in the information submitted to the TFPOP (UNECE, 2006a) are summarized below.

Costs for industry (UNECE, 2006) are expected to be low as production and use is largely phased out. Substitution for remaining uses will therefore be low. Substitution in the military sector could though be costly, since there are no viable alternatives to this use today. Some costs will be associated with installation of air pollution control devices in recycling and shredder plants. A lot of recycling and shredder plants already have this kind of devices due to other restrictions. Some

costs will be associated with obligations on treating waste from recycling and shredder plants as hazardous waste. In many countries this obligation is already met, due to other hazardous substances in the waste.
Costs for consumers are expected to be very low (UNECE, 2006). **Costs for state budgets** associated with monitoring and controlling consumer products containing cPeBDE, especially imported products may exist but are not included in costs of using alternative substances in this study.

Although this information became available after the analysis in section 3.3.5.2 was made, it is important to note that assumptions made in this study are in line with the information submitted to the TFPOP in Tallinn..The way we summarize our final cost implication is a simplification of reality and some costs may be associated with replacing minor uses but flame retarding in PUR foam is by far and large the dominating use.

3.3.6 Short-chain chlorinated paraffins (SCCPs)

Chlorinated paraffins are chlorinated derivatives of n-alkanes, having carbon chain lengths ranging from 10 to 38, and a chlorine content ranging from about 30 to 70% (by weight). Short-chain chlorinated paraffins (SCCPs) are defined in the UNECE framework as having a carbon length of between 10 and 13 carbon atoms, and a chlorine content of between 30% and 70%, by weight (UNECE, 2003). The main uses of SCCPs are in metal working fluids, as plasticiser in paints, coatings and sealants, as flame retardant in rubbers and textiles, and in leather processing (fat liquoring).
In many cases a first option is to replace SCCPs with medium-chain chlorinated paraffins (MCCPs) or possibly long-chain chlorinated paraffins (LCCPs). However, Medium-chain chlorinated paraffins have a high acute toxicity towards aquatic organisms, a high fish bioconcentration factor and are poorly degradable (EC, 2005a). So, although the risk of using MCCPs to the atmosphere and long range atmospheric transport may be limited they appear to be less attractive replacements of SCCPs because of their aquatic toxicity. Therefore considerations in substitution of SCCPs include (OSPAR, 2001c):

- health and environmental risks associated with the substitute chemical (for example higher chain chlorinated paraffins);
- degree to which the substitute chemical fulfills technical and security demands;
- cost for substitution in proportion to health and environmental benefits; and
- SCCPs are often contaminants in MCCPs at a concentration of < 1%.

Various possible alternatives or substitutes to SCCPs by major usage category are listed in Table 11. Some are currently used as alternatives and others may be possible replacements. The Helsinki Commission report (EC, 2002a) stated that MCCPs is being used as replacements in the EU for SCCP as extreme pressure additives in metal working fluids, plasticisers in paint, and additives in sealants.

LCCPs have, at least in Sweden, been used in some demanding applications in metal working fluids instead of SCCPs. LCCPs are also suggested as replacements to SCCPs in the leather industry as well as in paint, coatings, and in sealants and rubber. No international reviews or assessments on LCCPs are available (EC, 2002a). It has been suggested that MCCPs and LCCPs should not be considered as possible alternatives to SCCPs, since MCCPs and LCCPs may also be persistent pollutants but an assessment of the toxicity of possible replacements of SCCPs listed in Table 11 is outside the scope of the present study. For a more detailed description of alternatives we refer to UNECE (2003).

Table 11 Possible Alternatives or Substitutes to SCCPs.

Use	Possible Alternative to SCCP
Extreme pressure additives in metal working fluids	MCCPs, LCCPs, alkyl phosphate esters, sulfonated fatty acid esters
Plasticizers in paints	MCCPs
Additives in sealants	MCCPs, LCCPs, phthalate esters
Leather industry	LCCPs, natural animal and vegetable oils
Paints, coatings	LCCPs, phthalate esters, polyacrylic esters, disobutyrate and phosphate and boron containing compounds
Flame retardant in rubber, textiles and PVC	Antimony trioxide, aluminum trioxide, acrylic polymers and phosphate containing compounds
Rubber	LCCPs

Source; OSPAR (2001c), EC (2002)

A few studies have reported information on SCCPs alternatives and associated costs. The UK Department of the Environment commissioned two reports that discuss alternatives to SCCPs used in leather processing (RPA, 1997a) and metal working (RPA, 1997b). OSPAR (2001c) and UNECE (2003) quote from these and some Canadian studies (e.g. Abt, 1996, quoted in UNECE 2003). However a more recent UK study RPA (2001) indicates that the picture is rapidly changing because many companies already move away from using SCCPs if they have good alternatives, anticipating a (future) ban on the use of SCCPs as a result of e.g. EC Directives and policies (EC, 2002a;b). Therefore the cost assessment is based on the latest study available because costs may be considerably less than quoted in earlier assessments due to less wide-spread use of SCCPs. In the following subsections costs are presented by application and summarized in section 3.3.6.6, Table 12.

3.3.6.1 Leather processing

SCCPs are used as inexpensive additives to fatliquors to provide greater product volume (i.e. they are bulking agents). Fatliquors replace oils that are lost during the tanning process, however it appears that no fatliquoring properties are conferred by the use of SCCPs. The only benefits that they offer over alternatives appear to be their odour-free nature and their reasonable price (RPA, 1997a). No tanner has indicated that the use of alternatives (any of a range of animal, vegetable or mineral oils) would alter the quality of end-products (RPA, 1997a). RPA (2001) concludes for the UK that there are no technical barriers to the substitution of SCCPs in leather processing fluids and any cost increases passed on to consumers will be very minimal. Based on this information it is concluded that the costs of a ban on use of SCCPs in leather processing will be negligible (or even non-existent). However, it cannot be excluded that in some countries the situation may differ from the UK situation but no additional information is available to make a more detailed assessment.

3.3.6.2 Metalworking

Previous cost estimates for a prohibition of the use of SCCPs in metalworking fluids in the UK (RPA, 1997a) were based upon a much greater level of use of SCCPs than is the current situation (RPA, 2001). A large number of formulating companies contacted in earlier surveys in the UK (RPA 1997a, b) were contacted again in 2000 (RPA, 2001). By far the majority of these companies have either already moved away from SCCPs, intend to do so in the future or have only relatively small uses remaining. Hence it seems that in the EU the use of SCCPs in metalworking in 2010 will be very limited if not negligible. There appear to be few technical obstacles to the substitution of SCCPs in metalworking fluids. However, there are likely to be annual costs associated with the increased price of alternatives to SCCPs. Where such alternatives are longer chain CPs, cost increases are expected to be fairly minimal: perhaps £12,500 per annum for the UK, on top of any cost increases that have already been incurred. Cost increases for a move to non-chlorinated alternatives could be much greater, perhaps £800,000 per annum due to increased fluid costs (RPA, 2001). Such cost increases will not be uniform since several companies have reported no increase, owing to their ability to negotiate a comparable price with the suppliers of CPs.
RPA (2001) concludes for the UK that the costs of a ban are expected to be significantly lower than estimated in 1997, given the trend away from use of SCCPs in metalworking fluids. There was a relatively low level of use in the UK metalworking industry in 1999 and that level will have declined further still for 2000. Indeed, it is understood that some of the major users in 1999 no longer use any SCCPs.

3.3.6.3 Sealants and adhesives

Given the decrease in use in the metalworking industry as a result of EC Directives this application may become the largest use of SCCPs at the current time or in the near future. However, use in this sector is also expected to decrease somewhat due to a general move away from polysulfide sealants (though the extent and timeframe of any such decrease are unknown) (RPA, 2001). For the UK, RPA (2001) concludes that a ban on SCCP use would entail significant one-off costs associated with research and development of substitutes, as well as ongoing costs related to the higher cost of other plasticisers (Table 12). It is likely that the current costs of a ban on SCCPs in sealants and adhesives would be equivalent to or greater than those for the metalworking sector. This is likely to be true since the replacements for SCCPs used in sealants are more expensive than those used in metalworking (often only around 5% cost increase for the former but up to 300% for the latter). Moreover, the reformulation costs associated with substitution of SCCPs in polysulfide sealants appear to be greater than those for metalworking fluids. It appears that reformulation is not yet possible for some companies and the need to reformulate would impose a significant economic impact for little environmental benefit. Certainly the balance of advantages and drawbacks for a ban on this use would be much less favourable than for use in metalworking fluids because no unacceptable risks were identified for use in sealants by the risk assessment (RPA, 2001).

3.3.6.4 Plasticiser and flame retardant in PVC products

Based upon consultation with the two major UK PVC and PVC compound manufacturers, it would appear that SCCPs are generally used because of their low price in comparison to other plasticisers (such as phthalates) and/or because they confer flame retardant properties which reduce/negate the need for the use of other flame retardants. In substituting SCCPs in some products, reformulation is not reported to be particularly difficult. However, it may result in potentially significant ongoing cost increases, especially where there is the need to use additional flame retardants and to reduce other filling materials. The total cost for the use of substitutes could be up to €60,000 per annum, based upon a usage of 45 tpa of SCCPs in PVC and assuming that it is used at a 10% concentration (RPA, 2001).

3.3.6.5 Flame retardant in rubber products

SCCPs as a flame retardant are mostly used in flame retarded conveyor belts for use in the mining industry. Significant investment and research would be required to substitute SCCPs in this application since no other substances are currently thought to be suitable for the products in question. However, the associated costs could not be quantified as alternatives have not been investigated in detail (RPA, 2001). A key factor in substitution of SCCPs in this application is the need to retain the same degree of flame retardancy.

3.3.6.6 Production, usage and calculation of costs of SCCPs replacements

Use of SCCPs in Europe decreased from 13,000 tonnes in 1994 to 4,000 tonnes in 1998 (OSPAR, 2001c). According to Chlorinated paraffin industry the production in the European Union in 2004 is down to approximately 1,000 tonnes per year. The use in metalworking fluids and fat liquoring of leather has completely ceased in 2004, in accordance with Directive 2002/45/EC (EC, 200b) The other uses represent less than 1,000 tonnes in 2004 (Chlorinated paraffin industry comments, 2005). These other uses are (EC, 2000);

- Flame retardants in rubber (proportion 1-10%), with applications mostly in high density conveyor belts.
- Plasticisers in paints and other coatings; also to improve water resistance, chemical resistance and nonflammability. Mostly industrial/specialist applications; used in proportions of 1-10% in paints.
- Additives in sealing compounds in building, automotive and industrial applications.
- Textiles - SCCPs used mostly in backcoating operations for sail cloths, industrial protective clothing, lorry tarpaulins, etc.

A summary of the cost implications of a ban on the marketing and use of SCCPs for the UK is provided in Table 12. Table 12 indicates the likely substitutes that would be used, the one-off costs expected for individual companies and the annual (substitution) costs for each sector. A crude simplification of Table 12 is that for Sealants and Adhesives, metal working fluids and PVC the costs of replacement are ~1,000€ / tonne SCCP replaced. For all other applications the additional costs are either unknown of very small.

The trend of decreasing usage of SCCPs is confirmed by RPA (2001) which reports that in the UK the use of SCCPs is rapidly declining and that the situation as in the 1990s is no longer representative for the period 2000-2020. We assume that in 2010 for the EU all usage of SCCPs has ceased at no additional costs for a revised POP Protocol because of autonomous developments (e.g. Directive 2002/45/EC). For the non-EU countries the costs listed in Table 12 are converted using the year 2000 UK consumption by application resulting in estimated costs/tonne of SCCP used. These cost figures are directly applied on the 2010 calculated SCCP consumption in non-EU25 countries. However, there is one important deviation from this approach; no costs are calculated for the use of SCCPs in sealants and adhesives because the fraction of SCCPs emitted to air from this application is presumed to be zero or negligible. Thus costs would be estimated but with no associated emission reduction. This may lead to a wrong perception of the costs associated with eliminating emissions to air of these substances.

Table 12 Summary of Current Cost Implications for the UK, SCCP use in the UK in 1999 and estimated replacement costs.

Application		**Substitute**	**One-off Costs (indiv. company)[d]**	**Ongoing Costs[a), d)]**	**UK Use 1999 (tonnes)[d]**	**Costs € / tonne replaced**
Sealants and Adhesives		(Phthalates, polymerics)	Up to €90,000 (one product)	Up to €440,000	235	1300
Flame Retardants (in Rubber)		None suitable at present[b]	Unknown but significant	Unknown	105	Unknown
Lava Lamps		Unknown	Unknown	Unknown	2	not relevant
MWF/Oil	Formulators	MCCPs/other	Up to €20-30,000 (several products)	€18,000 (MCCP) - €1200,000 (non-CP)[c]	416	100 (MCCP) 2500 (non-CP)
	Users		Unknown	€880,000		
PVC		MCCPs, phthalates, other flame retardants	Unknown	Up to €60,000	45	1000
Leather		Longer CP & non-CP	€0	€0		0
Sales through Distributors					368	Unknown
Unknown					63	Unknown

() Indicates potential substitute that may not be technically suitable

Costs converted to euros using the May 2006 currency rates (1 GBP = 1.47 EUR) and rounding of estimates

[a] Ongoing costs that are not yet being incurred based on use in 1999

[b] Has not been researched in detail by the company using the majority of the 105 tpa UK use.

[c] Companies have generally moved to longer chain CPs and thus the lower estimate is likely to be more accurate

[d] RPA (2001)

3.3.7 Perfluorooctane sulphonate (PFOS)

Perfluorooctane sulphonate (PFOS) is a fully fluorinated anion, the related compounds of which are members of the large family of perfluoroalkylated substances (PFAS). The EU Commission defines PFOS as “Perflourooctane sulfonates $C_8F_{17}SO_2X$ (X= OH, Metal, salt halide, amide, and other derivates including polymers). Releases of PFOS and its related substances are likely to occur during all stages of their life-cycle e.g. production, product application, distribution, industrial and/or consumer use and disposal.

The category of uses where there is no current use or where use is in the process of being phased out consists of carpets, leather, textiles, paper and packaging, coatings, cleaning products, fire fighting foam and pesticides/insecticides. Current small scale uses of PFOS are limited to those areas where suitable alternatives have not yet been identified. These include photographic/photo-finishing semiconductor applications and chemical formulation, metallic plating, some uses related to photography, photolithography and semiconductors, and hydraulic fluids used in aviation. The current demand (2004) in the European Union was estimated by RPA (2004) for the ongoing industrial/professional usage of PFOS and PFOS-containing substances (Table 13). In January 2005, OECD published a report with results from a survey on the production and use of PFOS and related substances in the OECD area. The responses to the survey were limited and only 10 OECD countries responded to the questionnaire. Eight of these countries were signature to the LRTAP POPs Protocol and one conclusion from the survey is that PFOS is still manufactured by Germany (20 – 60 tonnes in 2003) and Italy (< 22 tonnes in 2003) (OECD, 2005). The total production volume today in the LRTAP-region or globally is not known. Emissions of PFOS in UNECE-Europe from in-use products and current small-scale uses is also not known.

Table 13 Estimated current demand for PFOS-containing substances in the European Union.

Industry Sector	Quantity (kg/year)
Photographic industry	1,000
Semiconductor industry	470
Hydraulic fluids	730
Metal plating	10,000

Source; RPA (2004)

3.3.7.1 Management Options for PFOS and alternatives for existing uses

Recently Sweden submitted an “Exploration of Management Options for PFOS” to the fifth meeting of the LRTAP Task Force on Persistent Organic Pollutants, Tallinn, 29 May-1 June 2006 (UNECE, 2006b). This proposal contains an inventory of alternatives for existing uses:

- The possible alternatives identified for the photographic industry are: digital techniques, telomer-based products, C3 and C4 perfluorinated compounds, hydrocarbon surfactants and silicone products.
- According to the European Semiconductor Industry Association new techniques are being developed for semi-conductors where PFOS-related substances are not being used.
- For hydraulic oils a change in the formulation of the oil seems to be the only alternative solution. This will, however, demand a comprehensive testing together with an approval from the airplane manufacturers, which may take as long as 10 years, as safety standards within this industry are very high.
- For decorative chromium plating an alternative process already exists. In this process chromium(III) is used and no PFOS-chemicals are necessary. For hard plating, however, the process with chromium(III) does not function as well. Instead larger closed tanks, or increased ventilation combined with extraction of chromium(VI), are suggested as alternative solutions for the applications where a use of chromium(III) is not possible yet. In both cases exposure to chromium(VI), a known human carcinogen, will decrease, which is an added benefit of the alternatives.

As indicated earlier, the use of PFOS in carpets, leather, textiles, paper and packaging, coatings, cleaning products, fire fighting foam and pesticides/insecticides is being phased out. No detailed listing of the alternative is presented here.

The cost of eliminating the *surface protecting* uses of PFOS is very low since industry has largely substituted such use already (EU COM 2005). There are alternatives which are judged to be less environmentally damaging. For the other uses, photographic industry, photolithography and semiconductors, metal plating and hydraulic fluids there is a need for special conditions. It would be difficult to eliminate these uses at short notice. The Swedish Chemicals Inspectorate (2006) made an overview of costs for replacement or ban of PFOS uses and concluded that

PFOS is being phased out of several uses where alternatives are available. This has been done on a voluntary basis and the economic net costs are judged to be low. The main cost of elimination of PFOS uses relates to the loss of a few specific functions for consumers e.g. semiconductors and hydraulic oils in aviation. The economic impacts on producers of an elimination of PFOS production and use are small. The areas where time derogations may be needed are 1) photographic industry; 2) photolithography and semiconductors; 3) metal plating; and 4) hydraulic fluids (Swedish Chemicals Inspectorate, 2006). Derogations for these applications are needed because of difficulties with alternatives that cannot fulfil the technically required qualities of PFOS and/or extreme costs of technically acceptable alternatives. A further detailed discussion of the costs and alternatives of PFOS replacements is beyond the scope of the present study. For more information on this subject we refer to RPA (2004) and Swedish Chemicals Inspectorate (2006).

4. Results and Discussion

The cost and emission reduction of a set of revised emission limit values as well as specific product use targeted measures for POP and substances (possibly) proposed to be added to the POP Protocol is estimated for the year 2020. The assumption in the present study is that all measures of a possible revised POP Protocol will be implemented in 2010. The results are discussed in this chapter on an aggregated level by summing the remaining emissions, emission reductions, and associated costs for two country groups (Table 14) and highlight a few remarkable differences between countries. Since we assume full implementation of the POP Protocol by all countries in 2020, the major discrepancy between countries is the foreseen (mandatory) autonomous developments. Therefore, the split between countries is limited to two country groups. The relevance of this exercise is not to discuss the absolute emission level of a country group because the number of citizens covered, climatic conditions, prime economic activities etc. are fundamentally different between the two groups. The importance lies in the difference in associated costs and additional emission reduction achieved due to differences in autonomous policies implemented in both country groups. Especially the obligation of the EU25+ countries to implement the IPPC Directive and some specific Directives on product use is important.

Table 14 Country groups, number of countries in group and country group code.

Description	Nr. Of countries	Group Code
All countries that implement EC Directives (EU25, NOR, CHE)	27	EU25+
No implementation of EC Directives	17	Non-EU25+

4.1 Emission reduction and associated costs upon revision of the POP Protocol for unintentional released substances from stationary sources

Four stationary emission source categories (Industrial solid waste incineration, Iron and steel production in electric arc furnaces, Magnesium production and Secondary aluminium production) have been selected for assessing the reduction potential and cost of further emission control measures. Selection was based on the extend of the remaining contribution for POPs and substances possibly to be added to the Protocol after full (all European UNECE countries) implementation of the present UNECE POP Protocol. The aggregated results (reduction potential and annual cost) for the EU(25) plus Norway and Switzerland (EU25+), and the other UNECE Member States is presented in Table 15. The emission information for all sources is summarized in Table 16.

Table 15 Costs of a possible revision of the POP Protocol for emission of unintentional by-products by source category in the EU25+ and Non-EU25+.

Category	**Costs (M€/yr)**		**Substance**	**Avoided Emission**	
	EU(25)+	**Non-EU25+**		**EU(25)+**	**Non-EU25+**
Industrial solid waste incineration	191	9	PCDD/F (g Teq/yr)	442	93
			PCB (kg/yr)	78.7	0.6
			HCB (kg/yr)	124.3	29.0
			PCN (kg/yr)[a)]	*115.2*	*27.7*
Electric arc furnaces	691	238	PCDD/F (g Teq/yr)	268	252
			PCN (kg/yr)[a)]	18	13
Magnesium production	1.9	1.5	*HCBD (kg/yr)*[a)]	*1326*	*1075*
Secondary aluminium production	0	0	HCB (kg/yr)	1093	30

a) PCN and HCBD are not included in the 1998 POP Protocol

Table 16 Emission of unintentional by-products in 2020 in the EU25+ and Non-EU25+ after full implementation of the POP Protocol, avoided emission by substance and estimated remaining emission after implementation of a possible revision of the POP Protocol.

Substance	**Emission FIPOP 2020**		**Avoided Emission**		**Remaining emission**	
	EU(25)+	**Non-EU25+**	**EU(25)+**	**Non-EU25+**	**EU(25)+**	**Non-EU25+**
PCDD/F (g Teq/yr)	2059	1730	710	345	1350	1385
PCB (kg/yr)	3777	3637	73.8	0.6	3703	3637
HCB (kg/yr)[a)]	1398	124	1217	60	181	65
HCBD (kg/yr)	1446	1148	1326	1075	120	73
PCN (kg/yr)	179	103	133	41	46	63

Numbers may not add up exactly due to rounding to no decimals

4.1.1 Incineration of industrial combustible solid waste

This activity comprises the incineration (mostly without heat recovery) of all types of non-hazardous waste such as waste packaging and other waste paper, plastics and wood and other bio-wastes that are not included under “fuel wood”. This type of incineration does, in our view, not fall under one of the categories referred to by the EU Waste Directive or the POP Protocol. The stringent PCDD/F emission limit values (ELVs) for municipal and hazardous waste incineration do not seem to apply here and we have therefore assumed emissions after full implementation to be significant.

Maintaining the same ELV for the incineration of non-hazardous industrial waste as compared to other incineration activities (0.5 ug Teq/Nm^3) would bring about a total annual cost of about 200 M€, with the emphasis lying in the EU(25)+ rather than the other UNECE countries where land filling seems to be the preferred method of waste disposal (Table 15). A stringent ELV for industrial waste incineration will result in a 25% further reduction of PCDD/F emission and it will have significant side-effects for PCN and HCB. There are two major uncertainties to consider for assessing the potential for further emission reduction from industrial waste incineration i) How will the Directives be implemented, should industrial waste incineration be regarded separately from the incineration of other wastes or do the ELVs of the waste Directive also apply to this source category and, ii) the activity rates (how much waste is incinerated by industry) appear highly uncertain and not well documented.

4.1.2 Electric arc furnaces (secondary iron and steel industry; EAF)

In Phase 1 of the project (Denier van de Gon et al. 2005) it was not possible to assess the effect of implementing BAT on PCDD/F emission from Electric arc furnaces (see also Section 3.2.1). BAT under the current POP Protocol entails the use of a fabric filter. Although 0.1 ug Teq/Nm^3 may perhaps be achieved through the use of fabric filters, we have reckoned with the possibility of emissions exceeding this value. A possibility to further reduce PCDD/F emission is the injection of activated carbon upstream of the fabric filter. To implement this technology all over UNECE Europe significant investments (with a total approaching 1 billion €) would be needed. However, it should be noted that this measure will also remove gaseous Hg emissions if the particular PCDD/F source is also a source of Hg. Hence, there may be co-benefits of implementing this measure. The foreseen resulting PCDD/F emission reduction is more than 500 g Teq / yr (Table 15).

4.1.3 Primary Magnesium production

Several studies have demonstrated that the production of primary magnesium based on electrolysis of MgCl might result in a significant emission of chlorinated hydrocarbons, especially HCBD. This could be countered by injecting activated carbon in the waste gas of the chlorination furnace. A modest investment of 3.3 M€ would be required to implement this technology and virtual elimination of HCBD emission could thus be achieved (Table 15).

4.1.4 Production of secondary aluminium

The use of degassing agents such as hexachloroethane and chlorine causes emission of, among others, HCB. It is suggested that switching to other degassing agents will be virtually cost-neutral and would result in a HCB reduction in excess of 1 tonne (Table 15).

4.1.5 Summarized results for unintentionally released substances

The emission of unintentionally released substances after full implementation of the POP Protocol, avoided emission and remaining emission after a possible revision of the POP Protocol for the two country groups are summarized in Table 16. The anticipated costs, avoided emission and remaining emission of unintentionally released substances per country are presented in Table 17. The estimated costs and emission reduction vary highly between countries, and at a first glance may seem inconsistent. However, the patterns can be explained when analysing the underlying assumptions and methodology. For example the differences between Finland, France and Portugal for industrial waste incineration (Table 17) suggest an independent relationship between costs, reduced PCDD/F emission and remaining emission. The cost estimates are primarily dependant on the projected activity rates (6.1, 3.7, 0.75 tonnes for Finland, France and Portugal, respectively), therefore costs for Finland are estimated as being much higher than for Portugal. However, the relative contribution of industrial waste incineration for PCDD/F is also very different with 8%, 12% and 86% for Finland, France and Portugal, respectively. Hence, a strong reduction in PCDD/F emissions from industrial incineration brings about a major reduction in total Portuguese PCDD/F emission but can only modestly alter the Finnish or French total emissions. A similar example concerns PCDD/F emission from electric arc furnaces (EAFs) by Croatia, Italy and Luxembourg. Activity rates are 0.07 – 16.1 – 2.57 tonnes, respectively while the relative contribution by EAFs is 10%, 56% and 91%. Finally, POP emission factors for stationary sources are by nature extremely dependant on process characteristics and the degree of emission control. These parameters are known to be different between countries as well. More robust guide numbers for the costs versus remaining emissions are obtained from the average values for regions presented in Table 15.

4.1.6 Cost-effectiveness of measures to reduce unintentionally-released POPs or substances in a revised POP Protocol

The cost effectiveness of a measure is calculated as the achieved emission reduction divided through its cost. The outcome is called the specific cost and denotes the amount of emission avoided per monetary unit. The costs and avoided emission of measures aiming at PCDD/F emissions in Industrial waste incineration appear most attractive but are in the same order of magnitude as measures for electric arc furnaces;

- IWI costs are ~200 M€ reducing 535 g Teq PCDD/F, 143 kg PCN, 74 kg PCB and 153 kg HCB
- EAF costs are ~928 M€ reducing 520 g Teq PCDD/F and 31 kg PCN.

The local conditions as well as activity data for industrial waste incineration are rather uncertain and the figures should be interpreted with care. The cost effectiveness of PCDD/F emission reduction in a revised POP Protocol would be

0.37 M€/g Teq and 1.8 M€/g Teq for IWI and EAF, respectively. This can be compared with an earlier cost-effectiveness study in UNECE framework by Berdowski et al. (1998), although the comparability between the two studies is limited because of different starting points and conditions. In the earlier cost study for POP emission reduction, the cost effectiveness for PCDD/F was considerably more attractive e.g. 0.02 M€/g Teq PCDD/F for emission control in waste incineration (Berdowski et al., 1998). This is not surprising as any sensible emission reduction strategy will start with first implementing the most cost-effective measures.

Thus the comparison indicates that the cost effectiveness of the 1998 POP Protocol is more favourable than further reduction starting after full implementation of the POP Protocol. If HCBD would be included in the revised POP Protocol, the potential exists to reduce ~ 2100 kg HCBD emission from primary magnesium production at an annual cost of about 3M€.

The presented costs and emission reductions should be seen as indicative, the observed variation of cost-effectiveness between countries has a number of causes being

- The unique situation in each country in terms of (relative) importance of source contributions.
- Incomplete knowledge of variation of abatement costs between countries
- Uncertainties in (reporting of) activity rates and emissions.
- Uncertainty in TNO emission factors and estimated activity rates.
- The mixture of country estimates and expert estimates(to achieve completeness) causes inconsistencies in potential for emission reduction which propagates in cost-effectiveness estimates

Table 17 Costs of a possible revision of the POP Protocol for year 2020 emission of unintentional by-products by source category by country, avoided emission by substance and estimated remaining emission.

ISO3	**Industrial solid waste incineration**					**Electric arc furnaces**			**Magnesium production**		**Secondary aluminium production**		**Remaining emission (Country total)**				
	Costs	**Emission reduction**				**Costs**	**Emission reduction**		**Costs**	**Emission reduction**	**Costs**	**Emission reduction**					
		PCDD/F	**PCB**	**HCB**	***PCN***		**PCDD/F**	***PCN***		***HCBD***		**HCB**	**PCDD/F**	**PCB**	**HCB**	***HCBD***	***PCN***
	(M€/yr)	**(g Teq/yr)**	**(kg/yr)**			**(M€/yr)**	**(g Teq/yr)**	**(kg/yr)**	**(M€/yr)**	**(kg/yr)**	**(M€/yr)**	**(kg/yr)**	**(g Teq/yr)**	**(kg/yr)**			
ALB	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	5	0	0	0	0.2
ARM	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	5	0	0	0	0.2
AUT	0	0	0.0	0.0	0.0	11	1	0.1	0.0	0	-	0	33	49	38	0	2.7
AZE	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	15	0	0	0	0.8
BEL	0	0	0.0	0.0	0.0	31	5	0.1	0.0	0	-	0	24	58	2	0	1.0
BGR	2	7	0.1	28.5	16.0	3	7	0.1	0.0	0	-	1	127	126	0	0	0.7
BIH	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	7	46	0	0	0.3
BLR	0	0	0.0	0.0	0.0	12	4	0.7	0.0	0	-	0	4	1	0	0	0.3
CHE	0	0	0.0	0.0	0.0	9	1	0.0	0.0	0	-	3	8	4	0	0	0.4
CYP	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	5	1	0	0	0.2
CZE	3	5	21.6	0.5	4.5	4	20	0.2	0.0	0	-	11	294	126	1	8	1.2
DEU	0	0	0.0	0.9	0.0	130	12	0.6	0.3	216	-	442	165	903	50	20	8.5
DNK	3	3	0.3	0.1	0.6	7	1	0.0	0.0	0	-	16	47	11	2	0	0.5
ESP	0	0	0.0	0.0	0.0	105	66	5.7	0.0	0	-	25	22	29	3	8	1.4
EST	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	1	39	0	0	0.2
FIN	52	2	4.9	1.2	9.0	9	0	0.0	0.0	0	-	15	23	39	2	0	1.6
FRA	37	40	3.0	117.5	64.9	96	6	0.4	0.4	314	-	128	282	213	26	25	8.6
GBR	6	11	35.7	0.1	1.1	42	6	0.2	0.0	10	-	4	86	1088	2	9	2.5
GEO	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	8	0	0	0	0.4
GRC	0	0	0.0	0.0	0.0	14	15	0.8	0.0	0	-	0	24	132	0	0	1.3
HRV	4	0	0.3	0.0	7.4	1	6	0.0	0.0	0	-	0	58	9	0	0	0.3
HUN	1	49	0.1	0.3	2.5	5	5	0.3	0.0	0	-	17	11	62	2	0	0.6
IRL	1	3	0.1	0.0	0.2	5	0	0.0	0.0	0	-	0	10	7	0	0	0.5
ISL	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	1	0	0	0	0.0
ITA	16	14	1.5	0.4	2.7	116	65	6.3	0.0	0	-	220	54	144	25	8	5.2
KAZ	0	0	0.0	0.0	0.0	0	0	0.0	0.3	197	-	0	75	313	0	10	3.9
KGZ	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	-	0	11	7	0	0	0.5
LTU	1	40	0.1	0.2	2.0	0	0	0.0	0.0	0	-	0	5	16	0	0	0.3
LUX	0	0	0.0	0.0	0.0	26	2	0.1	0.0	0	-	0	5	1	0	0	0.2
LVA	0	9	0.0	0.0	0.4	0	0	0.0	0.0	0	-	0	6	2	0	0	0.3
MDA	0	0	0.0	0.0	0.0	7	0	0.4	0.0	0	-	0	3	10	61	0	0.3
MKD	0	0	0.0	0.0	0.0	1	1	0.1	0.0	0	-	0	4	25	0	0	0.2
NLD	0	0	0.0	0.2	0.0	3	0	0.0	0.0	0	-	75	26	46	9	0	0.7
NOR	5	1	0.5	0.1	0.8	8	2	0.0	1.1	787	-	115	34	5	13	41	0.5
POL	2	2	0.0	1.2	3.6	33	31	1.8	0.0	0	-	0	105	519	4	0	4.2
PRT	8	263	0.6	0.1	13.1	11	12	0.6	0.0	0	-	4	33	29	0	0	1.7
ROM	2	84	0.2	0.5	4.2	9	10	0.5	0.0	0	-	1	20	136	0	0	1.1
RUS	0	0	0.0	0.0	0.0	89	97	4.8	1.2	855	-	0	748	1969	0	53	38.3
SVK	0	0	0.0	0.0	0.0	4	14	0.2	0.0	0	-	0	17	123	0	0	0.3
SVN	0	0	0.0	0.0	0.0	6	1	0.3	0.0	0	-	0	1	19	0	0	0.2
SWE	56	1	5.3	1.3	9.7	17	1	0.1	0.0	0	-	18	30	39	2	0	1.4
TUR	0	2	0.0	0.0	0.1	105	115	5.8	0.0	0	-	0	119	323	0	0	6.0
UKR	0	0	0.0	0.0	0.0	10	11	0.6	0.0	0	-	29	156	429	3	8	8.0
YUG	0	0	0.0	0.0	0.0	1	1	0.0	0.0	23	-	0	22	243	0	1	1.2
Total	199	535	73.8	153.1	142.8	928	520	30.8	3.4	2401	-	1123	2734	7340	246	193	108.9

4.2 Emission reduction and associated costs upon revision of the POP Protocol for emission due to product use

The associated costs for emission reduction of POPs or substances under consideration for possible addition to the POP Protocol mostly involves estimating the cost of substitution of the substance by another product or substance that is considered not or less harmful for the environment. A total of nineteen substances have been regarded with respect to replacement possibilities and costs. Two substances (OctaBDE and PFOS) have recently been proposed for addition to the POP Protocl but are not further discussed here. However, brief emission and replacement costs related data are discussed in sections 3.3.5. and 3.3.7.

For eleven of these substances, usage in the form of a product is believed to be negligible in Europe in 2020 (Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Hexabromobiphenyl, Mirex, Toxaphene, DDT, Heptachlor and PCBe). No further attention will be given to these substances, illegal emissions or re-emissions cannot be excluded but are outside the scope of the present study.

For the POP HCH (including Lindane) and the substances Dicofol, Endosulfan and SCCPs emission and/or usage is expected to occur in 2020 and (some) costs of replacement of the substance are expected. For these substances (at least some form of restricted) usage is currently still allowed by UNECE and EU legislation. The methodology to estimate the costs of substituting these products by an alternative product or substance is described in detail in chapter 3. The aggregated result for two country groups within UNECE Europe is presented in Table 18. Total UNECE-Europe emissions due to product use in 2020 after full implementation of the POP Protocol and after a possible revision of the POP Protocol according to the measures proposed in this study are summarized in Table 19.

For two substances under consideration for possible addition to the POP Protocol (PeBDE and PCP) the usage may not be zero in 2020 but replacement by an alternative is estimated to be cost-neutral, as is documented in chapter 3. For two POPs (PCB and HCB) all fresh use is projected to have completely ceased as a result of implementation of the current POP Protocol and autonomous measures.

Table 18 Usage in 2020 of Lindane, PCB, HCB, Endosulfan, Dicofol, SCCPs, PeBDE and PCP in the EU25+ and Non-EU25+ countries and estimated replacement costs due to a possible revision of the POP Protocol.

Substance		**EU(25)+[a]**			**Non-EU25+**		
		Usage	**Cost (M€/yr)**		**Usage**	**Cost (M€/yr)**	
		(tonnes/yr)	**Lower**	**Upper**	**(tonnes/yr)**	**Lower**	**Upper**
Lindane	- Seed Treatment	27	0.3		14	0.2	
	- Soil Incorporation	27	1.5		14	0.8	
	- Wood Preservation	419	6.7		0	0	
PCB		0	0		0	0	
HCB		0	0		0	0	
Endosulfan		516	10.3	79	1034	21	81
Dicofol		250	22.5	114	67	6	15
SCCPs		150	0.0	1	67727	7	169
PeBDE		NA / NR[b]	0	0	NA / NR[b]	0	0
PCP		NA / NR[b]	0	0	NA / NR[b]	0	0

[a] EU(25) plus Norway and Switzerland

[b] Not available / not relevant. The emissions originate from in-use products.

Table 19 UNECE-Europe emission of POPs and substances (possibly) proposed for addition due to product use in 2020 after full implementation of the POP Protocol, avoided emission by substance and estimated remaining emission after implementation of a possible revision of the POP Protocol and autonomeous measures.

Substance	**Emission FIPOP 2020**	**Avoided Emission**	**Remaining emission**
		(tonnes/yr)	
Lindane	255	255	0
Endosulfan	775	775	0
Dicofol	32	32	0
SCCPs	114	114	NE[a] (0)
PeBDE	9.8	9.8	NE[a] (0)
PCP	705	498	207

PCB and HCB emissions due to product use are zero or negligible see Table 16 for emissions from other sources.

[a] Not estimated. Known emission sources within UNECE-Europe are reduced to zero by proposed measures but emissions from e.g. goods imported from outside the UNECE cannot be excluded.

4.2.1 HCH including Lindane

The usage of Lindane usage is restricted at this moment by the 1998 POP Protocol but the allowed applications may still result in usage of ~500 tonnes/yr. Based on data for the year 2000 (Denier van der Gon et al., 2005), application in wood preservation is the most important use. Total replacement costs for Lindane by an alternative are estimated to approach 10M€ with wood preservation accounting for almost 7M€. Only 10% of the costs are expected outside the EU(25)+. However, it is deemed likely that future EU legislation will be more stringent, possibly resulting in a total EU-wide ban on Lindane before 2020. If so the costs made by a revision of the POP Protocol will be substantially reduced as this emission reduction seen from UNECE perspective will be an autonomous development.

4.2.2 Endosulfan

The usage of Endosulfan was ~1500 tonnes/yr in 2000 (Denier van der Gon et al., 2005) and it is expected that without additional policy Endosulfan will still be used in similar quantities in 2020 (Table 18). The total costs of replacement of Endosulfan are estimated to range between 31 and 160 M€ provided that no yield losses occur upon the usage of an alternative product. The cost range depends on whether or not an additional application of the alternative is necessary to achieve the same effect. Costs (and usage) are expected to be the highest outside the EU(25)+, this is simply related to larger estimated usage. It should be noted that the underlying activity data for usage of Endosulfan were available for OSPAR and EU15 countries but were estimated for other countries. Hence, better country usage data for the non-EU15, non-OSPAR countries could lead to substantial adjustment and improvement of usages and associated costs of replacement.

4.2.3 Dicofol

Replacement costs for Dicofol are estimated to be of the same order (29 – 129M€) as for Endosulfan. The given cost range is again depending on whether or not the pesticide’s application frequency has to be increased. This cannot be ascertained at this moment and may differ by country, region or crop involved. Costs are the highest for EU countries in Southern Europe where Dicofol is still widely used.

4.2.4 Short chain chlorinated paraffins

Usage of SCCPs was still considerable in Europe in 2000 (Denier van der Gon et al. 2005). However EU legislation will result in a EU-wide ban of SCCPs before 2020, at least for the usages causing emissions to air (e.g. EC 2002b; Directive 2002/45/EC). This means that incremental cost of SCCP replacement will only be significant outside the EU(25)+. In reference to air emission as well as costs, the most important application of SCCPs is metal working fluids (see Section 3.3.6). The range of replacement costs is depending on whether the use of medium and/or long chain chlorinated paraffins is acceptable as replacement for SCCPs metal working fluids. If not, replacement costs could be considerable (estimated at ~169 M€).

4.2.5 Product usage and costs by country

The detailed projected usage of Lindane, Endosulfan, Dicofol, and SCCPs by country and estimated replacement costs due to a possible revision of the POP Protocol are presented in Table 20. The costs to replace the pesticides under consideration (especially Dicofol and Lindane) appear to be restricted to a relatively smaller number of countries. Costs for Spain, Italy and France, Greece, Turkey, Ukraine and Russia are considerable while in most of the other countries costs appear to be negligible. Costs for replacement of Endosulfan and SCCPs are more distributed among countries with higher costs for countries with more inhabitants but this is partly due to the fact that a generic estimation method is used by lack of better national data. The estimation method disregards any country-specific circumstances that most likely will exist. The methodology as such can therefore by definition only give indicative first order estimates and the results should be seen in this respect. Again for a number of countries various costs will, from UNECE-perspective, not be made by a possible revision of the POP Protocol but due to compliance with other (autonomous) measures. The most clear example of this is the phase out of certain SCCP usage in the EU (EC, 2002b).

Table 20 Usage of Lindane, Endosulfan, Dicofol, and SCCPs by country and estimated replacement costs due to a possible revision of the POP Protocol.

ISO3	Lindane						*Endosulfan*			*Dicofol*			Sum of all pesticides	SCCPs		
	Usage (tonnes/yr)			Replacement cost (M€/yr)			Usage	Replacement cost (M€/yr)		Usage	Replacement cost (M€/yr)		Replacement cost	Usage Metal-working	Replacement cost (M€/yr)	
	Seed Treat-ment	Soil Incorp.	Wood Preser-vation	Seed Treat-ment	Soil Incorp	Wood Preser-vation	(tonnes/yr)	low	high	(tonnes/yr)	low	high	(M€/y)r	(tonnes/yr)	low	high
ALB	0	0	0	0.0	0.0	0.0	3	0.1	0.2	0	0.0	0.1	0.1 - 0.3	866	0.1	2.2
ARM	0	0	0	0.0	0.0	0.0	0	0.0	0.0	1	0.1	0.2	0.1 - 0.2	833	0.1	2.1
AUT	0	0	0	0.0	0.0	0.0	2	0.0	0.3	0	0.0	0.0	0 - 0.3	0	0.0	0.0
AZE	0	0	0	0.0	0.0	0.0	7	0.1	0.6	1	0.1	0.3	0.3 - 0.8	1931	0.2	4.8
BEL	0	0	0	0.0	0.0	0.0	18	0.4	3.5	0	0.0	0.1	0.4 - 3.7	0	0.0	0.0
BGR	0	0	0	0.0	0.0	0.0	8	0.2	0.6	9	0.8	2.0	1 - 2.6	0	0.0	0.0
BIH	0	0	0	0.0	0.0	0.0	2	0.0	0.2	0	0.0	0.0	0.1 - 0.2	956	0.1	2.4
BLR	0	0	0	0.0	0.0	0.0	30	0.6	2.3	0	0.0	0.0	0.6 - 2.3	2583	0.3	6.5
CHE	0	0	0	0.0	0.0	0.0	8	0.2	1.5	0	0.0	0.0	0.2 - 1.5	81	0.0	0.2
CYP	0	0	0	0.0	0.0	0.0	5	0.1	0.6	1	0.1	0.5	0.2 - 1.2	0	0.0	0.0
CZE	0	0	0	0.0	0.0	0.0	3	0.1	0.2	1	0.1	0.2	0.1 - 0.4	0	0.0	0.0
DEU	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
DNK	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
ESP	10	10	0	0.1	0.6	0.0	221	4.4	32.0	125	11.3	53.0	16.4 - 85.7	0	0.0	0.0
EST	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
FIN	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
FRA	0	0	80	0.0	0.0	1.3	71	1.4	14.0	14	1.3	8.2	4 - 23.5	0	0.0	0.0
GBR	7	7	52	0.1	0.4	0.8	1	0.0	0.2	1	0.1	0.6	1.4 - 2.1	0	0.0	0.0
GEO	0	0	0	0.0	0.0	0.0	4	0.1	0.3	0	0.0	0.0	0.1 - 0.3	1251	0.1	3.1
GRC	2	2	0	0.0	0.1	0.0	74	1.5	9.2	0	0.0	0.0	1.6 - 9.4	0	0.0	0.0
HRV	0	0	0	0.0	0.0	0.0	3	0.1	0.2	0	0.0	0.0	0.1 - 0.2	1067	0.1	2.7
HUN	0	0	0	0.0	0.0	0.0	7	0.1	0.6	5	0.5	1.4	0.6 - 2	0	0.0	0.0
IRL	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
ISL	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	69	0.0	0.2
ITA	8	8	273	0.1	0.4	4.4	91	1.8	15.4	95	8.6	47.5	15.3 - 67.8	0	0.0	0.0
KAZ	0	0	0	0.0	0.0	0.0	14	0.3	1.1	1	0.1	0.2	0.3 - 1.3	4170	0.4	10.4
KGZ	0	0	0	0.0	0.0	0.0	7	0.1	0.6	0	0.0	0.1	0.2 - 0.6	1168	0.1	2.9
LTU	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
LUX	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0 - 0.1	0	0.0	0.0
LVA	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
MDA	0	0	0	0.0	0.0	0.0	10	0.2	0.8	0	0.0	0.0	0.2 - 0.8	1104	0.1	2.8
MKD	0	0	0	0.0	0.0	0.0	2	0.0	0.2	2	0.1	0.4	0.2 - 0.6	509	0.1	1.3
NLD	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.4
NOR	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
POL	0	0	0	0.0	0.0	0.0	10	0.2	0.9	0	0.0	0.0	0.2 - 0.9	0	0.0	0.0
PRT	0	0	15	0.0	0.0	0.2	3	0.1	0.3	5	0.4	1.6	0.8 - 2.2	0	0.0	0.0
ROM	1	1	0	0.0	0.1	0.0	21	0.4	1.7	15	1.3	3.3	1.8 - 5	0	0.0	0.0
RUS	0	0	0	0.0	0.0	0.0	425	8.5	33.1	4	0.3	0.8	8.8 - 34	36383	3.6	91.0
SVK	0	0	0	0.0	0.0	0.0	2	0.0	0.2	1	0.1	0.3	0.1 - 0.5	0	0.0	0.0
SVN	0	0	0	0.0	0.0	0.0	2	0.0	0.2	1	0.1	0.3	0.1 - 0.5	0	0.0	0.0
SWE	0	0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0	0.0	0.0
TUR	12	12	0	0.1	0.7	0.0	241	4.8	18.7	25	2.2	5.5	7.8 - 25.1	0	0.0	0.0
UKR	0	0	0	0.0	0.0	0.0	246	4.9	19.2	6	0.5	1.3	5.5 - 20.5	12249	1.2	30.6
YUG	1	1	0	0.0	0.0	0.0	10	0.2	1.0	4	0.3	1.1	0.6 - 2.1	2657	0.3	6.6
Total	41	41	419	0.5	2.3	6.7	1550	31	160	317	29	129	69 - 299	67877	6.8	170

4.3 Emission reduction over time by substance

The possible revision of the POP Protocol would involve a third step in the emission reduction of the persistent organic pollutants adopted by the 1998 UNECE POP Protocol. The emission reduction achieved by a possible revision of the POP Protocol can be placed in perspective by comparing the remaining emissions of the relevant POPs for the year 2000, year 2020 assuming full implementation of the 1998 UNECE POP Protocol and, year 2020 assuming full implementation of a revised POP Protocol according to the proposed measures in this study. To keep an overview emissions are grouped by source category according tot the higher aggregated source categories defined by Denier van der Gon et al. (2005) (Table 21). The estimated and/or projected UNECE-Europe emissions of HCB, PCB, HCH, PCDD/F and PCN in 2000 and the two policy scenario's for 2020 are presented in Figure 1 to Figure 5, respectively.

Table 21 Aggregated source categories defined in the year 2000 POP inventory (Denier van der Gon et al. 2005).

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

Projected HCB and PCB emissions in the year 2020 will effectively be reduced by implementation of the 1998 POP Protocol (Figure 1, Figure 2). The added value of additional measures for these substances is rather limited. However, all reductions of POP emissions are beneficial for the environment and, if costs are acceptable, these can be pursued. For HCB this applies to the residual 2020 emission from secondary aluminium smelters (under "Industry"). In case the revised Protocol would include a ban on chlorine and chlorine compounds in this sector, remaining HCB emission will be effectively reduced to only 2 percent of the year 2000 emissions. UNECE-Europe PCB emissions in 2020 are at ~5% of its 2000 level.

Projected Lindane emission in 2020 assuming full implementation of the POP Protocol does not deviate from estimated 2000 emissions because all emission reduction of Lindane according to the POP Protocol has taken place before 2000 (Denier van der Gon et al., 2005). The estimated remaining emissions in 2000 and 2020 assuming full implementation of the POP Protocol are so-called allowed or exempted usages of lindane, the use of other HCH isomers has ceased already. A revision of the POP Protocol and/or future autonomous measures involving a further restriction or ban on lindane use is needed to eliminate the remaining Lindane emissions (Figure 3).

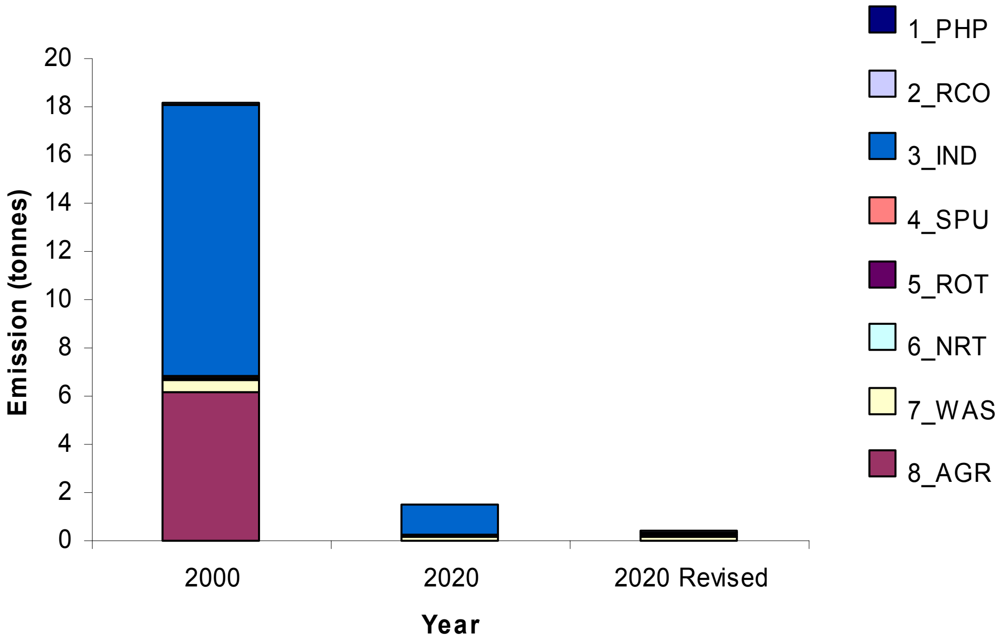

Figure 1 *HCB emissions in UNECE Europe in 2000 and projected emissions in 2020 assuming full implementation of the POP Protocol and subsequent revision of the POP Protocol according to measures proposed in this study.*

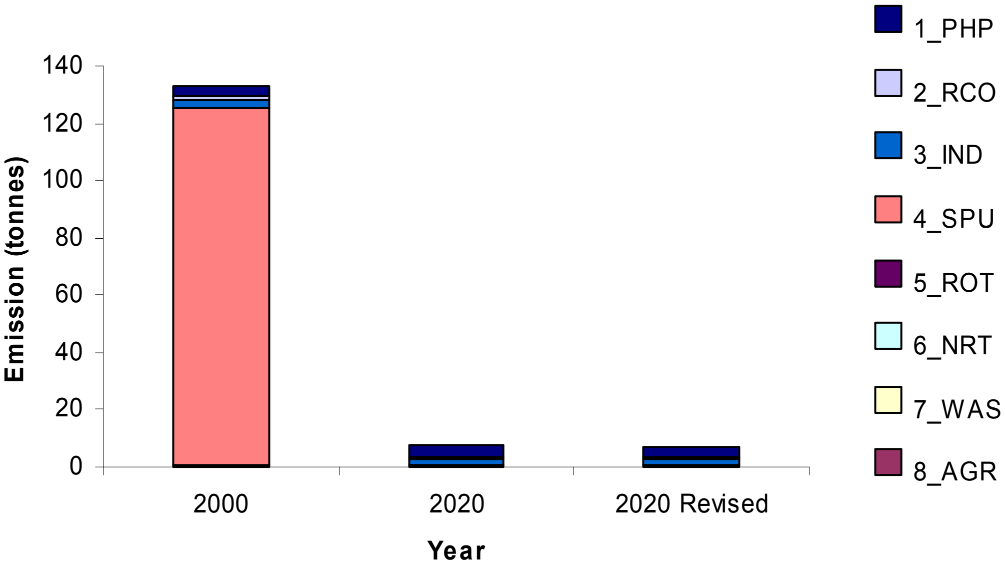

Figure 2 *PCB emissions in UNECE Europe in 2000 and projected emissions in 2020 assuming full implementation of the POP Protocol and subsequent revision of the POP Protocol according to measures proposed in this study.*

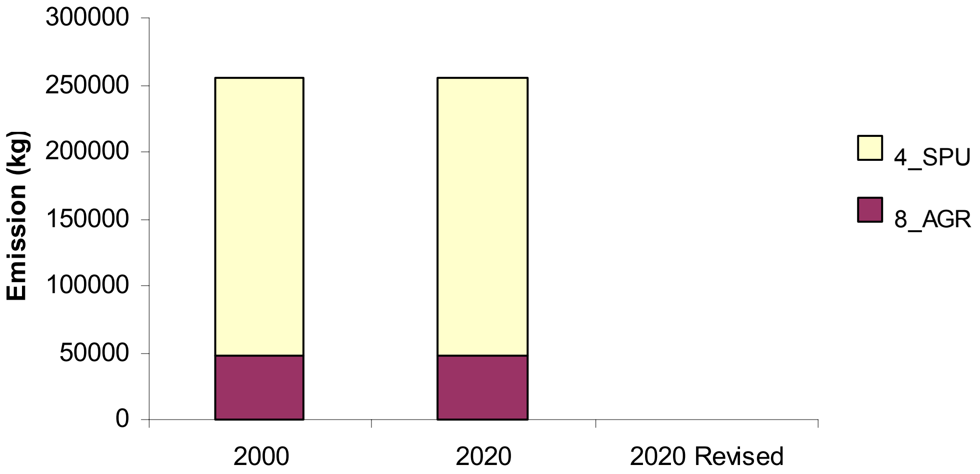

Figure 3 *Lindane emissions in UNECE Europe in 2000 and projected emissions in 2020 assuming full implementation of the POP Protocol and subsequent revision of the POP Protocol according to measures proposed in this study.*

The unintentional-released emissions of PCDD/F and PCN originate from the same processes and sources. Therefore, the estimated year 2000 and projected 2020 emissions show the same temporal pattern as well as source contribution profile (Figure 4 and Figure 5). The year 2000 emissions are effectively addressed by full implementation of the 1998 POP Protocol resulting in substantial lower projected emissions of PCDD/F and PCN in 2020 (Figure 4 and Figure 5, see also Denier van der Gon et al., 2005) for a more detailed discussion). However, a limited number of sources with noteworthy contributions remain. If the POP Protocol would be revised according to the measures selected in this study the emission from the secondary iron and steel industry and the incineration of non-hazardous industrial waste would be reduced further, resulting in another ~30% reduction for PCDD/F and PCN of the projected 2020 emissions assuming full implementation of the current POP Protocol.

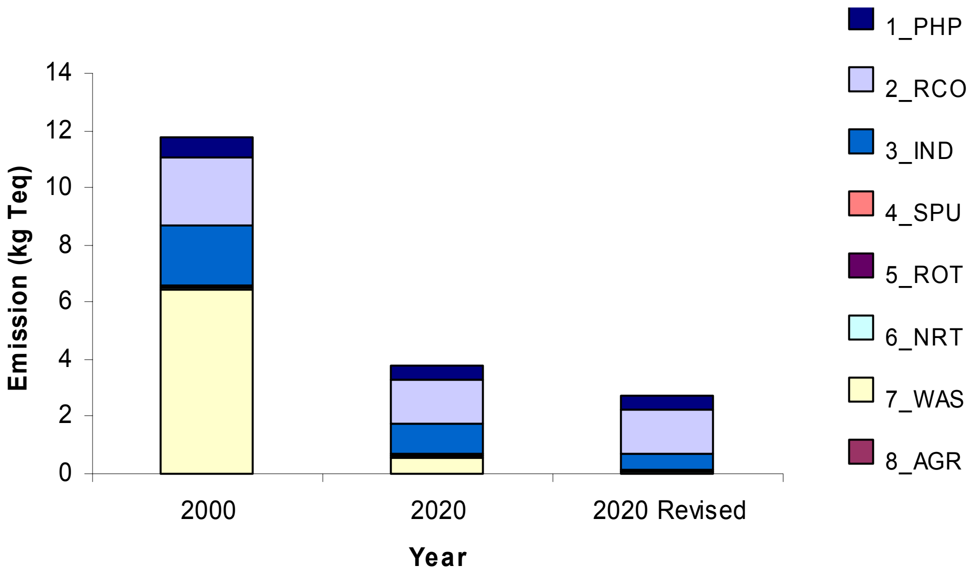

Figure 4 *PCDD/F emissions in UNECE Europe in 2000 and projected emissions in 2020 assuming full implementation of the POP Protocol and subsequent revision of the POP Protocol according to measures proposed in this study.*

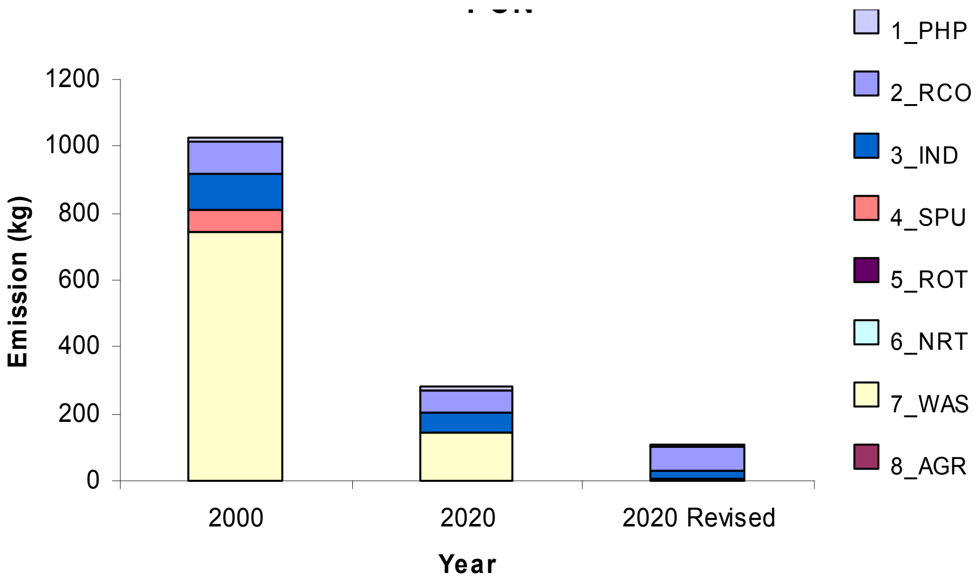

Figure 5 *PCN emissions in UNECE Europe in 2000 and projected emissions in 2020 assuming full implementation of the POP Protocol and subsequent revision of the POP Protocol according to measures proposed in this study.*

4.4 The contribution of residential sources

In consultation with the commissioner of the project it has been decided not to evaluate the potential of emission reduction by addressing residential /domestic combustion sources. The main motivation for this choice is the foreseen difficulties in legislation, implementation and enforcement of relevant emission control measures. Measures for this source category quickly come down to e.g. a ban on using wood for residential heating or a forced abandoning of coal stoves. This is not deemed realistic at present; although individual countries (may) have/plan subsidized stove-improvement programmes and/or implement regulations for new heating stoves aimed at optimizing the unit's combustion conditions. The most effective way to reduce POP emission would be the replacement of coal, oil and wood by natural gas as suggested by Denier van der Gon et al. (2005). It should be clearly noted that excluding this sector in the revision of the POP Protocol does not imply that it is not an important source category. After a possible revision of the POP Protocol this sector will be dominating the emissions of PCDD/F and PCN as can be seen from Figure 4 and Figure 5. Further emission reduction of PAH after full implementation of the POP Protocol has not been investigated because the emissions are completely dominated by the residential sector (see Table 5).

4.5 Spatial distribution of emission data

Transport modelling of pollutants requires, amongst others, detailed knowledge of POP input to the atmosphere. To facilitate the modelling of POP distribution over Europe upon revision of the POP Protocol, the 2020 emission data assuming full implementation of the revised POP Protocol should be spatially distributed in the form of a grid. However, as most suggested measures involve a ban on the use of the substance, emissions due to a revised POP Protocol will effectively become zero. Presence of the substance in the atmosphere will than be dominated by re-emissions, illegal emissions and emission from outside of the UNECE domain. Only for PCDD/F emission preparation of a spatially distributed emission map was deemed useful at present because for other substances the remaining emissions are either zero or very small e.g. due to a ban on substance use or have changed little compared to full implementation of the POP Protocol because the major sources have not been addressed in the revised Protocol (PAHs). The procedure for producing such maps is described in detail by Denier van der Gon et al. (2005). The spatial distribution of remaining PCDD/F emission in UNECE-Europe upon revision of the POP Protocol is shown in Figure 6. By subtracting the remaining emissions from the original emissions after full implementation of the 1998 POP Protocol, a spatial impression is obtained where the emission reductions are localized (Figure 7). It should be noted that for some countries (e.g. Turkey) the spatial patterns as shown in Figure 6 and Figure 7 are not good due to a lack of information on the localization of emission sources. In such cases the (anthropogenic) emissions are distributed by population.

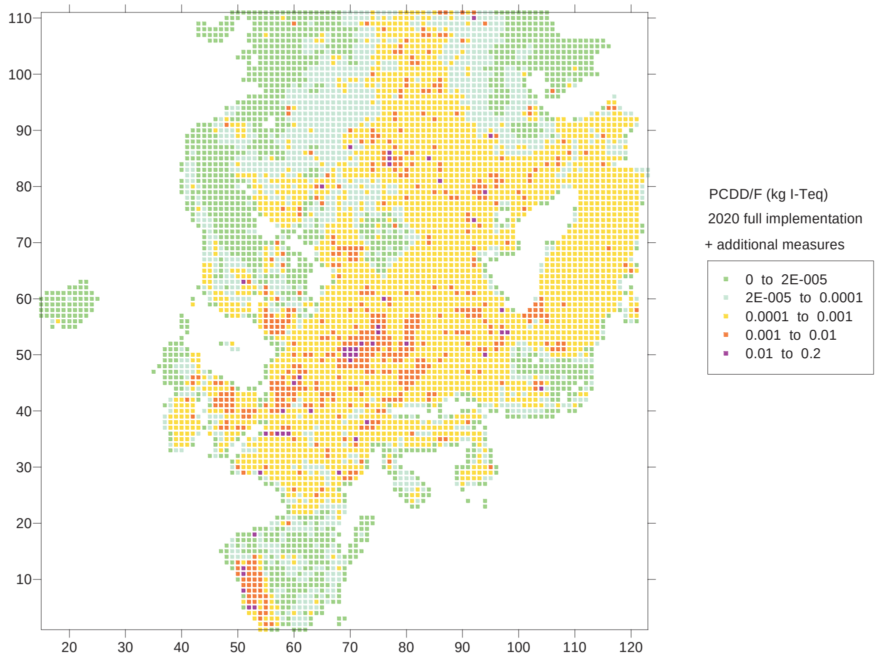

Figure 6 *Distribution of the emissions of PCDD/F over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 assuming full implementation of a revised POP Protocol.*

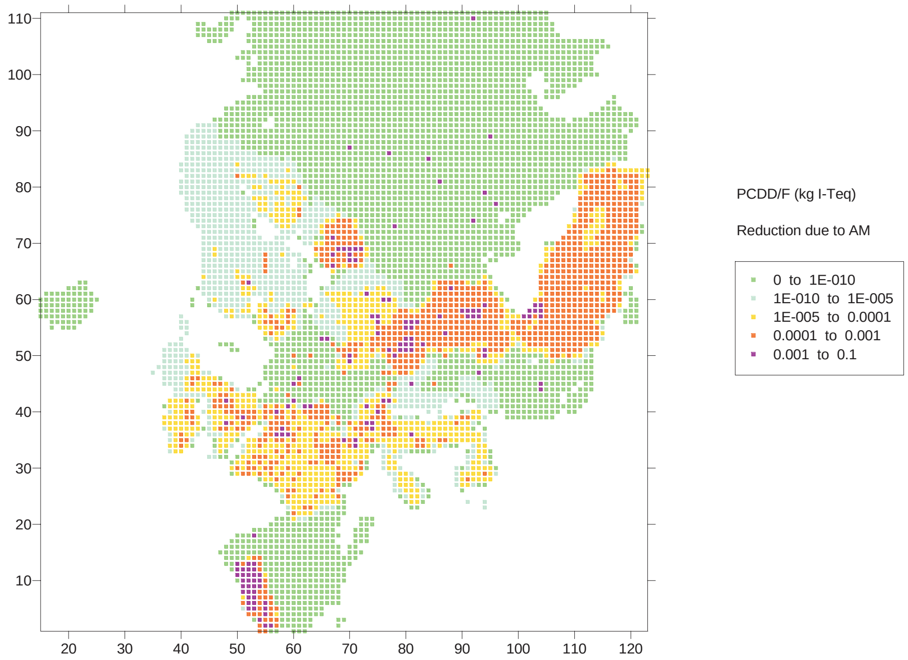

Figure 7 *Spatial distribution of the PCDD/F emission reduction over the 50 x 50 km^2 EMEP grid for UNECE-Europe in 2020 after full implementation of a revised POP Protocol.*

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6. Authentication

Name and address of the principal:
Netherlands Ministry of Housing, Spatial Planning and the Environment

Names and functions of the cooperators:
H.A.C. Denier van der Gon
A.J.H. Visschedijk
M. van het Bolscher

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

Date upon which, or period in which, the research took place:
November 2005 – July 2006

Signature:	Approved by:
H.A.C. Denier van der Gon project leader	H.S. Buijtenhek manager