GLOBAL POPs INVENTORIES

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Abstract
Inventories of persistent organic pollutants (POPs) have attracted scientific and political interest because they form the basis for release reduction measures that are often required by countries as part of their reporting obligations within multilateral environmental agreements. Despite this political context, first POPs inventories have been developed by scientists and are steadily improving as scientific knowledge and technology improve. POPs inventories vary by nature since they serve different purposes and therefore are hard to compare. Presently, global coverage cannot be achieved for any of the POPs. However, regional information has been obtained and experiences with the development of POPs inventories as well as first conclusions from these results can be used for future developments and especially for release reduction measures.

Introduction
Inventories of chemical pollutants are highly appreciated and often requested by researchers, policy makers, and the general public. More recently, their development have become legally obligation in international treaties. Inventories of persistent organic pollutants (POPs) have been published for emissions or releases on global, regional or local scales since approximately twenty years [1]. For researchers in different fields, quantitative information on the formation and release of chemicals are needed for, *e.g.*, impact and risk assessment, modeling, determination of time and spatial trends. For policy makers, inventories often serve as the basis for their national reporting to international organizations, for decision making as to release reduction measures such as implementation of best available techniques and environmentally sound practices, or legislation, and standard setting. They also serve as the basis for other than natural science disciplines such as economics or health. Most inventories provide quantitative information in relation to a reference year. As with any other inventory, POPs inventories follow the following equation:

$$\text{Annual release}_{POP} = \Sigma\text{Source strength x Activity}$$

Typically, the source strength is given in units of mass per input or output, *e.g.*, mg per kg of pollutant released per ton of feed material or per ton of output. As can be seen from the above equation, the annual release of a source is the result of multiplying the source strength and the activity at national level (local or global, respectively). As a consequence, any uncertainty related to the activity will have the same impact on the result as choosing an inadequate emission factor or uncertainties related to the analytical determination of the emission. This paper attempts to give a snapshot on POPs release inventories that have been developed and published.

Materials and Methods
Information on POPs inventories has been compiled from various sources, especially the national reporting of member countries or parties to international conventions such as the Stockholm Convention on Persistent Organic Pollutants[2], the UNECE Convention on Long-Range Transboundary Pollution (POPs Protocol), and the European Pollutant Emission Register (EPER)[3]. Further information was obtained from relevant publications in either the published literature or national reports. It should be noted that these inventories have been developed utilizing different methodologies and serve different purposes as to their political mandates.

1. European Community: POPs in Waste for Its Member States

The Technical Guidelines for the environmentally sound management for POPs waste for use under the Basel and Stockholm Conventions contain a provisional definition for the "low POP content" in waste, which is set to 15 μg TEQ kg^{-1} for PCDD/PCDF and to 50 mg kg^{-1} for each of the POPs pesticides, PCB, and HCB[4]. Countries were encouraged to test these guidelines. At the regional level, the European Commission has commissioned a study to compile and evaluate existing data on the occurrence and levels of POPs in different waste categories and put them into relation to the "low POPs content"[5].

2. EMEP-UNECE: POPs Emissions to Air for Parties to the POPs Protocol of the LRTAP Convention

The 1979 Geneva Convention on Long-range Transboundary Air Pollution (LRTAP) Convention has been extended by the 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs), which presently has 28 Parties

(10 August 2007). The Protocols ultimate objective is to eliminate any discharges, emissions, and losses of POPs. The Protocol bans production and use of some products right away; other POPs are scheduled for elimination at a later stage or severely restricted in use. The Protocol obliges Parties to reduce their emissions of PCDD, PCDF, polycyclic aromatic hydrocarbons (PAH), and hexachlorobenzene (HCB) below their levels in 1990 (or an alternative year between 1985 and 1995)[6].

3. European Union: The European Pollutant Emission Register (EPER)

The European Pollutant Emission Register (EPER) is the first European-wide register of industrial releases into air and water. It provides data for large and medium-sized point sources in the industrial sectors covered by the IPPC Directive; however, it excludes emissions from the transport sector and from most agricultural sources. According to EPER Decision, Commission Decision of 17 July 2000, EU Member States have to produce a triennial report, which covers the emissions of 50 pollutants from those industries whose emissions exceed established threshold values[7]. From the POPs, PCDD/PCDF and HCB are included in EPER.

4. Stockholm Convention on POPs

The Convention requests Parties to develop and maintain inventories of releases of PCDD/PCDF and HCB and PCB as unintentionally generated POPs to all media. A reporting format has been adopted by the Conference of the Parties at its 2nd meeting. Presently, the Convention has 147 Parties but not all of them have submitted information as to the national releases of unintentional POPs. In addition, inventories have been developed in Toolkit pilot projects or as part of the nation implementation plan that have not yet been submitted to the Stockholm Convention Secretariat. Many Parties have applied UNEP's Toolkit for Identification and Quantification of Dioxin and Furan Releases[8]; others have reported based on measured data or other methodology. The Stockholm Convention Secretariat also maintains registers for specific exemptions and for DDT.

5. PCDD/PCDF Inventories Prepared for Purposes Other than Multilateral Environmental Agreements

In this paper, only the most recent inventory from the United States is included for reference[9]. For all other inventories, other sources of information[1] should be consulted since no newer information was found.

Results and Discussion

The study of the European Union[5] on POPs above the low POP content of 15 µg TEQ kg^{-1} of waste for PCDD/PCDF estimated that 85,900 tons of waste containing 1,649 g I-TEQ are generated annually by the 25 Member States (Table 1). According to the EU estimate, 89.6% of the PCDD/PCDF in waste in the EU would not need to be addressed by the Stockholm and Basel Conventions. The lower part of Table 1 shows the amounts of waste and the percentages that would be covered if the lower POP content would be changed to lower limits. Similar estimates for PCB, HCB, and the POPs pesticides are include in the report as well. However, although the database for PCDD/PCDF with respect to information on dioxin concentrations in waste and on activity was considered medium and good, the uncertainties for the other POPs are much higher.

Table 1: Estimated amounts of waste and of PCDD/PCDF in waste in the territory of the European Union[5]

Source of Waste	Waste Volume		PCDD/PCDF	
	kt a^{-1}	% of total	g I-TEQ a^{-1}	% of total
Total waste generated	390,769		15,880	100%
Total of waste above > 15 µg TEQ kg^{-1}	85.9		1,649	
MSWI - APC residues	21.0	24.4%	532	32%
Power generation – biomass	26.6	31.0%	415	25%
EAF- dusts	33.4	38.9%	585	35%
Sec Al filter dust	4.3	5.0%	106	6%
Sec copper	0.6	0.7%	11	1%
	Waste > low POP content		Waste < low POP content	
	g I-TEQ a^{-1}	% of total	g I-TEQ a^{-1}	% of total
Low POP content >15 µg TEQ kg^{-1}	1,648	10.4%	14,232	89.6%
Low POP content >10 µg TEQ kg^{-1}	3,059	19.3%	12,822	80.7%
Low POP content >1 µg TEQ $^{kg-1}$	3,957	24.9%	11,923	75.1%
Low POP content >0.1 µg TEQ kg^{-1}	4,851	30.5%	11,029	69.5%

For the UNECE region, the data compilation according to the guidelines on emission inventories under the

Aarhus POPs Protocol for the year 2000 is shown in Table 2. The compiled national total emissions from the second annual review of emissions data reported under the UNECE LRTAP Convention are a mix of official data and expert estimates to achieve completeness. The report indicates that official data cover PCDD/F emissions relatively well but for all other substances the coverage is poor. However, there are some caveats such as that official emission data reported with no sectoral split were not considered because no assessment of the completeness of such a national estimate could be made. The authors stress that it is of utmost importance that official inventories provide insight in the sources covered by the reporting to assess completeness of the reporting and maintain comparability with other national reporting.

Table 2: National emissions of POPs in UNECE Europe in 2000 [10]

Country	HCB kg a^{-1}	PCB kg a^{-1}	PCDD/PCDF g TEQ a^{-1}	Country	HCB kg a^{-1}	PCB kg a^{-1}	PCDD/PCDF g TEQ a^{-1}
Albania	0	26	43	Ireland	0	49	30
Armenia	0	405	47	Iceland	0	34	2
Austria	42	948	50	Italy	2,863	3,648	245
Azerbaijan	0	810	98	Kazakhstan	1	1,202	288
Belgium	28	3,698	114	Kyrgyzstan	1	244	62
Bulgaria	54	229	233	Lithuania	0	406	33
Bosnia-Herzegovina	0	187	67	Luxembourg	0	68	10
Belarus	0	1,147	13	Latvia	0	267	54
Switzerland	31	1,154	17	Rep. of Moldova	66	194	4
Cyprus	1	45	11	FYR Macedonia	0	86	28
Czech Republic	202	2,091	744	Netherlands	598	164	31
Germany	2,870	29,887	406	Norway	1,273	275	34
Denmark	162	695	78	Poland	46	2,265	334
Spain	6,082	5,868	143	Portugal	96	385	844
Estonia	0	223	3	Romania	14	496	400
Finland	226	1,917	31	Russia	8	31,016	2,732
France	1,800	13,380	560	Slovak Republic	1	133	146
UK	595	1,643	346	Slovenia	0	143	27
Georgia	0	582	67	Sweden	152	1,373	28
Greece	2	168	279	Turkey	2	326	1,012
Croatia	0	135	109	Ukraine	655	24,436	1,022
Hungary	279	323	687	FR Yugoslavia	0	552	172
Total	**18,150**	**133,323**	**11,684**				

At the level of the European Union, the reporting for the year 2004 included data from all Member States from approx. 12,000 industrial facilities. For HCB, the EPER reporting thresholds are 0.01 tons per year for emissions to air and 0.001 tons per year for releases to water. For 2004, a total of twelve facilities reported annual releases resulting in emissions of 76.0 kg a^{-1} into air (4 countries), 14.5 kg a^{-1} direct to water (4 countries), and 7.5 kg a^{-1} indirect to water (1 country). For the dioxin inventory, there is an EPER threshold only for emissions to air, which 0.001 kg I-TEQ per year; subsequently, no water releases were reported. The air emission inventory for PCDD/PCDF reported data from 98 facilities located in twelve Member States (Table 3).

Table 3: Reported releases of PCDD/PCDF to air for member States of the European Union according to EPER reporting (g I-TEQ a^{-1}); reference year = 2004

Country	Emission to air (g I-TEQ a^{-1})	% of EU total	Country	Emission to air (g I-TEQ a^{-1})	% of EU total
Austria	1.47	0.1%	Italy	92.1	6.5%
Hungary	2.50	0.2%	Germany	106.11	7.5%
Portugal	11.6	0.8%	France	212.93	15.0%
Sweden	20.6	1.4%	Poland	246	17.3%
Belgium	29.68	2.1%	Spain	285.6	20.1%
United Kingdom	68.92	4.8%	Czech Republic	345	24.3%
Total	**1,422.51**	**100%**			

At the global level, information on production and use of POPs can be retrieved from the Stockholm Convention Secretariat's website. Presently, the information is still scarce and does not provide information on the global production and use of POPs. For example, the register on specific exemptions[11] only contains notifications for three POPs, namely chlordane (China and Botswana), DDT (China and India), and mirex (China and Australia). The DDT Register[12] presently has entries from 12 Parties that may be in need to use DDT in the public health sector but only three countries may produce DDT for public heath purposes (China, Ethiopia, and India).
In 2007, Fiedler published an overview on PCDD/PCDF inventories[1]. Therein included is information on dioxin emissions from 23 countries that were either published in the open literature or that were taken from government reports. Adding up the emissions of these 23 countries, a range between 7,500 and 13,000 g TEQ released to air per year was obtained. Table 4 does not include the above mentioned results because they are largely outdated but lists PCDD/PCDF inventories for countries that have based their inventories mainly on measured data or have estimated the releases with methodologies other than the UNEP Toolkit. The data, except for the United States of America (US-EPA, 2006), are taken from the National Implementation Plans (NIPs) that were reported to the Secretariat of the Stockholm Convention in 2006/2007. Most countries have reported emissions to air only; only a few did estimate releases to water or in residues. In order to calculate an "inhabitant equivalent of TEQ releases", totals have been set to the same value in case only air emissions were reported. For Sweden and Denmark, the upper-bound estimates were included.

Table 4: Estimated releases of PCDD/PCDF to air and as totals applying non-Toolkit methodology

		Annual Release				Reference Year
		(g TEQ a^{-1})		(µg TEQ $person^{-1}$ a^{-1})		
Country	Pop.*mio.	Air	Total	Air	Total	
Bulgaria	7.761	255	255	32.9	32.9	2003
Canada	31.6	164	186	5.2	5.9	1999
Czech Rep	10.206	185	185	18.1	18.1	2004
Denmark (max)	5.4	689	689	128	128	2002
Japan	127	400	402	3.1	3.2	2003
Latvia	2.3	27.4	54.8	11.9	23.8	2004
Netherlands	16.5	39.8	39.8	2.4	2.4	2003
Norway	4.61	33.0	33.0	7.2	7.2	2003
Romania	21.8	574	574	26.3	26.3	2002/03
Sweden (max)	9	106	284	11.7	31.6	1990s
Switzerland	7.36	23	23	3.1	3.1	1990
USA	298.44	1,308	1,422	4.4	4.8	2000
Total / Mean		3,804	4,148	21	24	

UNEP's Toolkit is widely used by especially developing countries to develop their first PCDD/PCDF release inventories. Table 5 presents the information obtained to date based on information found in the NIPs, national reporting, or through Toolkit projects, most of them implemented by UNEP Chemicals. It shows the emissions to air and the aggregated releases to all vectors (air, water, land, product, and residue). Table 5 also includes a "population equivalent" in µg TEQ per year, which may be helpful to put results into perspective and which can also serve as an orientation for a country if the own estimate fits into the scale of estimates from other countries. It has been recognized that the large range of emission factors (across six order of magnitude in the Toolkit) and the different units the emission factors are based upon (tons, hectare, or terajoule but often national data are stored in liter, gallon, kilogram, square kilometers, *etc.*) may easily cause mathematical errors. As can be seen, the largest releases originate from China but when taking into account a total population of approximately 1.3 billion, the mean emission to air only results in 4 µg TEQ $person^{-1}$ and a^{-1} and thus, is among the lowest of all inventories. The same applies to the total releases.

Table 5: Annual releases of PCDD/PCDF (g TEQ a^{-1}) to air and for all release vectors (as total) estimated with UNEP's Toolkit

Country	Pop.*mio.	Annual Release (g TEQ/a)		Annual Release (µg TEQ/person*a)		Reference Year
		Air	Total	Air	Total	
Albania	3.07	58.7	143	19	47	2004
Argentina	37.4	706	2,133	19	57	2003
Armenia	2.98	5.49	52.0	1.8	17	2001
Australia	19.7	495	1,799	25	91	2002
Belarus	9.75	36.6	142	3.7	15	2004
Brunei Darussalam	0.340	0.749	1.40	2.2	4.1	2001
Burkina Faso	12.5	300	785	24	63	2002
Burundi	7.02	190	195	27	28	2004
Cambodia	13.4	273	607	20	45	ukn
Chile	15.1	51.7	85.7	3.4	5.7	2003
China	1,300	5,043	10,237	3.9	7.9	2004
China-Hong Kong	6.90	2.70	20.8	0.4	3.0	2003
Côte d'Ivoire	17.3	416	432	24	25	2002
Croatia	4.50	116	168	26	37	2001
Cuba	11.2	195	319	17	28	2000
Djibouti	0.60	50.8	119	85	199	2003?
Ecuador	12.2	65.0	97.6	5.3	8.0	2002
Estonia	1.42	14.0	29.2	9.9	21	ukn
Ethiopia	71.1	154	215	2.2	3.0	2003
Fiji	0.81	11.2	19.2	14	24	2002
Jordan	5.30	64.3	81.6	12	15	2003
Lebanon	3.75	79.0	166	21	44	2004
Lithuania	3.48	37.4	56.9	11	16	2005
Macedonia	2.05	163	175	80	85	2001
Mali	10.5	35.0	39.5	3.3	3.8	2005
Mauritius	1.21	19.6	30.4	16	25	2003
Moldova	4.3	13.5	776	3.1	180	2001
Morocco	29.9	167	425	5.6	14	2003
New Zealand	4.08	32.3	80.3	7.9	20	1998
Nicaragua	5.48	266	638	49	116	2004
Niue	0.002	0.392	0.563	181	259	2004
Paraguay	5.20	70.7	156	14	30	2002
Philippines	84.5	328	534	3.9	6.3	1999
Samoa	0.169	1.05	1.38	6.2	8.2	2004
Seychelles	0.081	4.10	5.41	51	67	2003
Slovenia	2.01	6.19	30.4	3.1	15	2005
Sri Lanka	19.9	172	257	8.6	13	2002
Tanzania	34.6	517	947	15	27	ukn
Thailand	62.4	286	1,070	4.6	17	200X
Tunisia	9.91	139	209	14	21	2004
Uruguay	3.30	18.7	48.5	5.7	15	2003
Vietnam	78.4	16.0	68.8	0.20	0.88	2002
Zambia	10.3	290	483	28	47	2004
TOTAL		**10,911**	**23,877**	**12**	**21**	

Despite all the efforts and the tremendous amount of information that has been produced and is being gathered at national, regional, and global levels, it is still not yet possible to estimate the amounts of POPs produced intentionally or their amounts in use or in storage. It is also not yet possible to estimate the releases of POPs at the global level. Whereas the situation seems more complete for PCDD/PCDF than for any of the other POPs, there is still significant information missing. For example, more than 100 countries have not published any quantitative information with regards to POPs inventories. On the other hand, inventories are dynamic and as

national reporting under the various international environmental agreements makes steady improvements and science improves to refine analytical measurement and estimation methods, more and better information can be expected in the future.
Nevertheless, it has to be taken into account that the requirements for each of these treaties are different and the basis for inclusion of activities and releases differ widely. Therefore, information contained in regional inventories cannot easily be transferred to global inventories. Within inventory development, some prefer to report ranges of emissions rather than central estimates what further complicates the compilation of global inventories. Finally, all inventories have inherent uncertainties and there are still many open scientific questions as to the accurate determination of emission factors but also as to the determination of the national activity especially for diffuse and unregulated sources such as open burning of biomass or waste in the case of PCDD/PCDF.
Despite the above caveats, POPs inventories are useful tools and in many cases describe a country's (or region's) present situation as to the presence of POPs at their sources and form the basis for the implementation of methods to prevent formation and release of POPs or to reduce their releases through application of environmentally sound management methods for these chemicals or application of best available techniques and best environmental practices.
However, developers and users of POPs release inventories should note that release inventories quantify the amount of a given POP released from the sources and do not make statements on human health risks or environmental/ecotoxicological risks or damages that may result from these emissions into any of the receiving compartments.

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