



Atmospheric emissions of polychlorinated dibenzo(p)dioxins and dibenzofurans in the Baltic Sea region 1990–2023


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Atmospheric emissions of polychlorinated dibenzo(p)dioxins and dibenzofurans in the Baltic Sea region

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2025

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Key Message

Annual atmospheric emissions of polychlorinated dibenzo(p)dioxins and dibenzofurans (PCDD/Fs) in the HELCOM Contracting Parties have decreased by 29% during the period from 1990 and 2023.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This Fact Sheet presents the levels, spatial distribution, and temporal trends of PCDD/Fs emissions from anthropogenic sources in the HELCOM Contracting Parties, which are used in modelling PCDD/Fs deposition to the Baltic Sea (cf. BSEFS “Atmospheric deposition of polychlorinated dibenzo(p)dioxins and dibenzofurans to the Baltic Sea”).

Policy relevance and policy references

The updated Baltic Sea Action Plan outlines the ecological objective that concentrations of hazardous substances in the environment should be close to background levels for naturally occurring substances. HELCOM Recommendation 42-43/6 identifies HELCOM priority substances for the Baltic Sea.

At the European level, the relevant policy for controlling PCDD/Fs emissions to the atmosphere falls under the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). The CLRTAP Protocol on Persistent Organic Pollutants (1998) targets a list of harmful organic substances, including PCDD/Fs. Among its key obligations is the requirement to reduce PCDD/Fs emissions to levels below those recorded in 1990. The Protocol, which entered into force in 2003, has been signed or ratified by 40 countries.

Assessment

Annual anthropogenic PCDD/Fs emissions to the atmosphere from HELCOM Contracting Parties decreased by 29% between 1990 and 2023 (Figure 1). A substantial decline in emissions occurred during the early part of the time series, with particularly pronounced reductions between 1990 and the mid-2000s. After about 2004, the rate of decline slowed. The spatial distribution of PCDD/Fs emission fluxes for 1990 and 2023 is shown in Figure 2, with the highest fluxes observed along the southern and western coasts of the Baltic Sea.

The emissions trend in each sub-period was analysed using the Mann-Kendall test [Gilbert, 1987; Connor et al., 2012; Pohlert, 2023]. PCDDFs emissions show a statistically significant decreasing trend (negative monotonicity, $p < 0.001$, $\tau = -0.889$). Between 1990 and 2003, a stronger decline occurred, with an average annual decrease of about 2.4 g TEQ¹ per year (Sen's slope, $p = 0.001$, 95% confidence interval). In the subsequent period (2004-2023), the annual decline slowed to about 0.3 g TEQ (Sen's slope, $p < 0.001$, 95% confidence interval).

The time series of annual PCDD/Fs emissions from the HELCOM Contracting Parties is presented in Figure 3. Among these countries, Germany saw the largest reduction in emissions (86%), followed by Sweden (72.5%) and Denmark (62.6%). The lowest decline of national PCDD/Fs emissions was reported by Poland (30%). No data on temporal changes in PCDD/F emissions in the Russian Federation were available.

In 2023, total anthropogenic PCDD/Fs emissions from the HELCOM Contracting Parties amounted to 2243 g TEQ², with the largest contributors being Russia (80%), Poland (12%), and Germany (5%).

Given the generally high uncertainties of emission estimates and the lack of reported data for the Russian Federation (see Metadata), the total estimate of PCDD/Fs emissions from the HELCOM countries and its temporal changes remains highly uncertain.

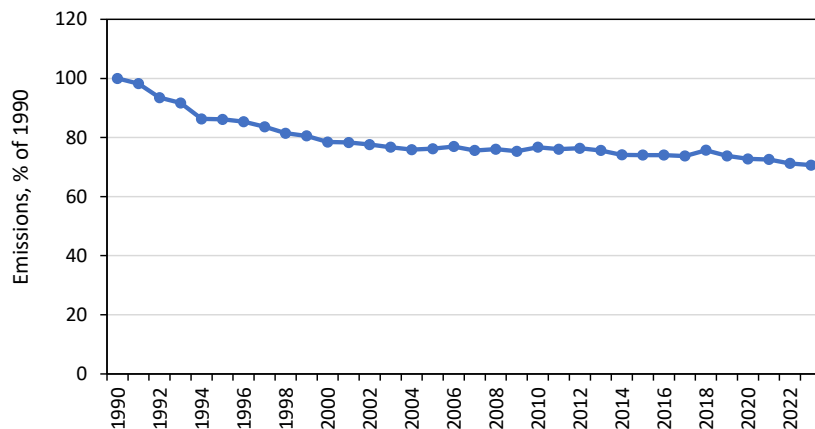


Figure 1. Relative changes of total annual emissions of PCDD/Fs to the atmosphere from the HELCOM Contracting Parties in period 1990-2023 (% of 1990).

PCDD/Fs are pollutants of global concern due to their persistence in the environment, toxic effects, and potential for long-range transport. Current levels of PCDD/F pollution are considerably influenced by secondary emissions resulting from their historical accumulation in soils, water, and other environmental compartments. Model estimates of secondary PCDD/Fs emissions are described in the BSEFS “Atmospheric Deposition of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans to the Baltic Sea.”

¹ See Metadata for an explanation of the g TEQ units

² See Metadata for an explanation of the g TEQ units.

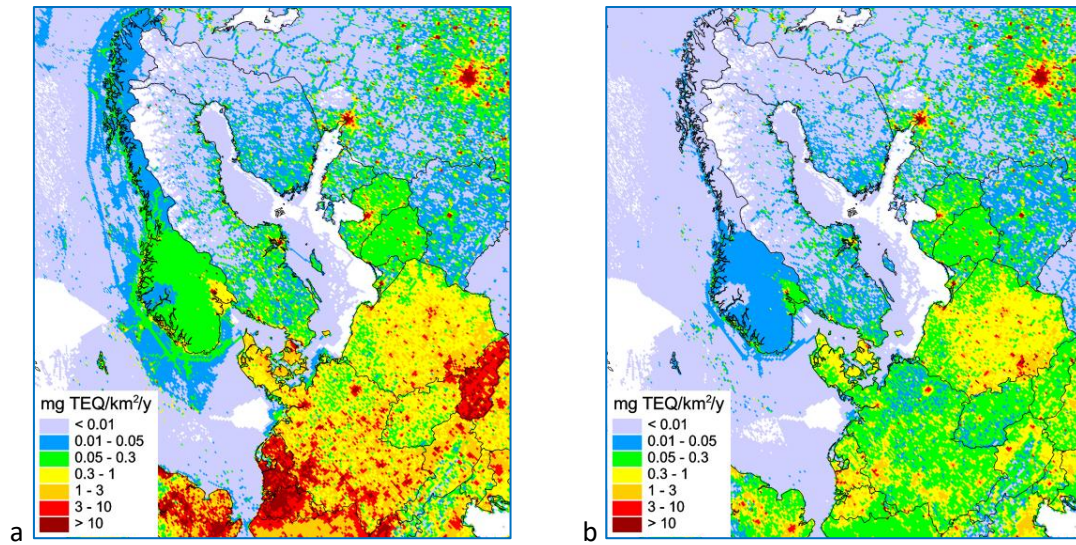


Figure 2. Spatial distribution of annual anthropogenic PCDD/Fs emissions to the atmosphere in the Baltic Sea region in 1990 (a) and in 2023 (b).

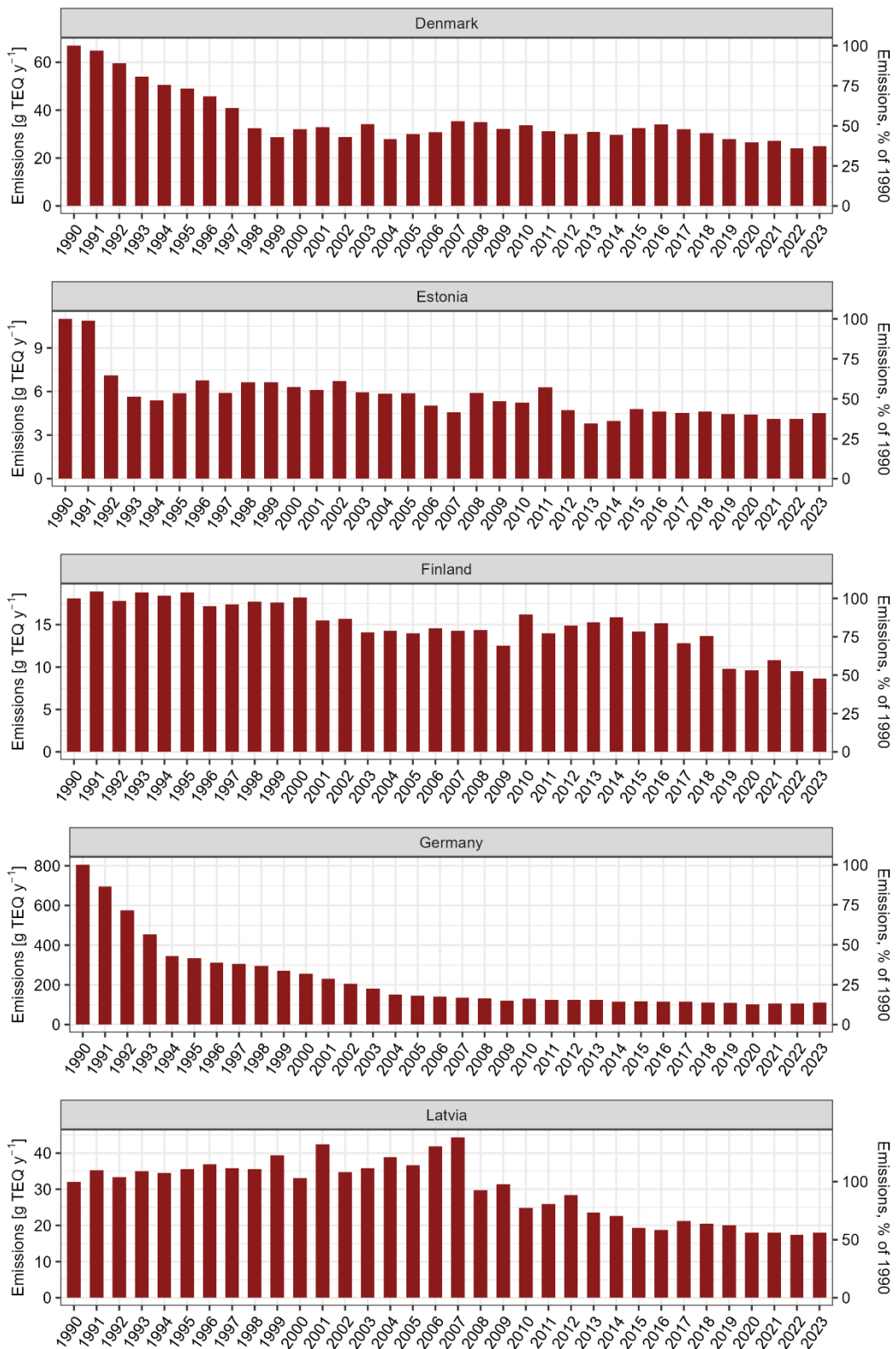


Figure 3. Atmospheric PCDD/Fs emissions from HELCOM Contracting Parties during the period 1990-2023. The emission data for Russia pertains to the territory within the EMEP domain.

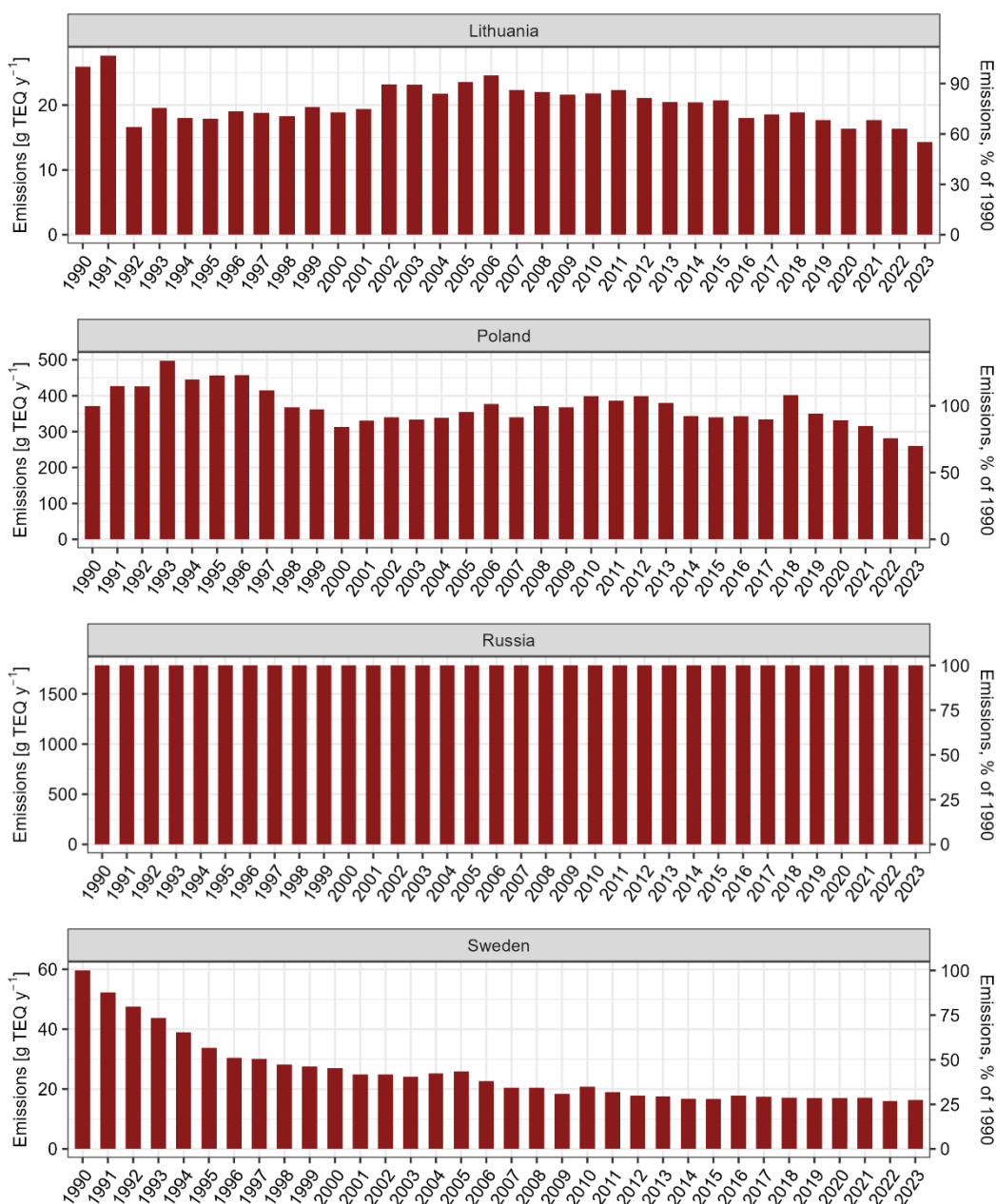


Figure 3 (continued). Atmospheric PCDD/Fs emissions from HELCOM Contracting Parties during the period 1990-2023. The emission data for Russia pertains to the territory within the EMEP domain.

The main contributions to total emissions of PCDD/Fs from HELCOM Contracting Parties in 1990 came from industrial sources (31%), public power generation (30%), other stationary combustion (26%), and waste incineration (9%) (Figure 4). In 2023, the contributions from industrial sources and public power generation decreased to 9% and 6%, respectively, leading to an increased share of other stationary combustion (56%) and waste incineration (24%).

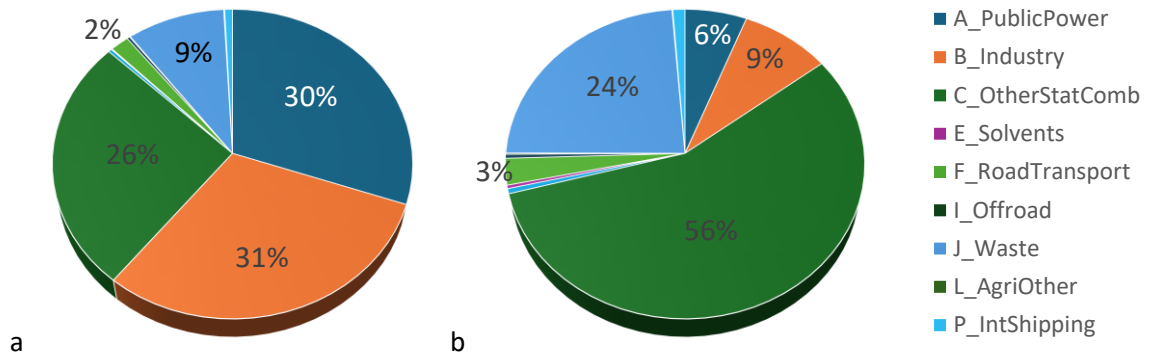


Figure 4. Contribution of emission sectors total annual emissions of PCDD/Fs to the atmosphere from the HELCOM Contracting Parties in 1990 (a) and 2023 (b).

Data

Numerical data on anthropogenic PCDD/Fs emissions from HELCOM Contracting Parties are provided in the table below.

Table 1. PCDD/Fs emissions from anthropogenic sources in HELCOM Contracting Parties from 1990 to 2023. Units: g TEQ y⁻¹.

Year	DK	EE	FI	DE	LV	LT	PL	RU	SE	HELCOM	Others
1990	66.9	11.0	18.1	805	32.1	25.9	372	1784	59.6	3175	13472
1991	64.8	10.9	18.9	697	35.3	27.6	427	1784	52.4	3118	11280
1992	59.6	7.1	17.8	576	33.3	16.6	426	1784	47.6	2968	11278
1993	54.0	5.7	18.8	453	35.0	19.5	497	1784	43.8	2911	10937
1994	50.5	5.4	18.4	344	34.5	18.0	446	1784	39.0	2740	11329
1995	48.9	5.9	18.8	334	35.6	17.9	456	1784	33.7	2735	11524
1996	45.7	6.8	17.2	312	36.9	19.0	458	1784	30.5	2710	10457
1997	40.9	5.9	17.4	307	35.8	18.8	415	1784	30.1	2655	10289
1998	32.4	6.6	17.7	295	35.6	18.3	367	1784	28.2	2585	9003
1999	28.6	6.6	17.6	271	39.4	19.7	362	1784	27.6	2557	8386
2000	32.1	6.3	18.2	257	33.1	18.9	314	1784	26.9	2491	8929
2001	32.9	6.1	15.5	231	42.4	19.4	330	1784	24.9	2487	8043
2002	28.9	6.7	15.7	206	34.8	23.2	340	1784	24.9	2465	7853
2003	34.1	6.0	14.1	181	35.8	23.1	333	1784	24.1	2436	7703
2004	27.9	5.9	14.3	153	38.9	21.7	338	1784	25.2	2409	7582
2005	30.0	5.9	14.0	145	36.6	23.6	354	1784	25.8	2419	6941
2006	30.8	5.0	14.6	142	41.9	24.6	377	1784	22.7	2443	6288
2007	35.5	4.6	14.3	135	44.3	22.3	340	1784	20.5	2401	6103
2008	35.1	5.9	14.4	132	29.7	22.0	371	1784	20.4	2415	5577
2009	32.3	5.3	12.5	119	31.3	21.6	367	1784	18.4	2392	3706
2010	33.7	5.3	16.2	130	24.9	21.8	399	1784	20.7	2436	3953
2011	31.1	6.3	14.0	125	25.9	22.3	386	1784	19.0	2414	3894
2012	30.1	4.7	14.9	124	28.4	21.1	399	1784	17.8	2424	3994
2013	31.0	3.8	15.3	125	23.6	20.5	380	1784	17.6	2401	3721
2014	29.7	4.0	15.9	116	22.6	20.4	344	1784	16.8	2354	3614
2015	32.6	4.8	14.2	118	19.3	20.7	340	1784	16.7	2351	3802
2016	34.0	4.6	15.2	116	18.7	18.0	342	1784	17.7	2351	3757
2017	32.1	4.5	12.8	115	21.2	18.6	335	1784	17.4	2341	3683
2018	30.4	4.6	13.7	111	20.5	18.9	402	1784	17.2	2403	3657
2019	27.9	4.4	9.8	110	20.0	17.7	351	1784	16.9	2342	3734
2020	26.6	4.4	9.6	102	18.0	16.4	332	1784	16.9	2310	3736
2021	27.2	4.1	10.8	108	18.0	17.7	316	1784	17.1	2303	3595
2022	24.1	4.1	9.5	108	17.5	16.4	282	1784	16.0	2262	3514
2023	25.0	4.5	8.7	111	18.0	14.3	261	1784	16.4	2243	3539

Metadata

Technical information

1. Source:

Meteorological Synthesizing Centre East (MSC-E) of EMEP, Centre on Emission Inventories and Projections (CEIP) of EMEP.

2. Description of data:

Official PCDD/Fs emissions data reported by the HELCOM Contracting Parties to the UN ECE Secretariat were used for the calculations and the emission trend analysis. These data are collected and made available by the EMEP Centre on Emission Inventories and Projections (EMEP/CEIP) (<http://www.ceip.at/>). No official emissions data on PCDD/Fs is available from the Russian Federation; instead, expert estimates by EMEP/CEIP are used for this country (Poupa, 2023).

3. Geographical coverage:

EMEP region.

4. Temporal coverage:

Data on annual PCDD/Fs emission totals are available for the period from 1990 to 2023 for all HELCOM Contracting Parties, with the exception of the Russian Federation. For the Russian Federation, a single available expert emission estimate provided by CEIP (Poupa, 2024) was applied for the entire period.

5. Methodology and frequency of data collection:

National PCDD/Fs emissions data are submitted annually by the Parties to the LRTAP Convention to the UN ECE Secretariat. The methodology combines measurements of atmospheric releases with estimates based on activity data and emission factors. The submitted data undergo a quality assurance and quality control process before being stored in the UN ECE/EMEP emissions database at the EMEP/CEIP Centre. Gaps in emissions data are filled with expert estimated using methodology described in (Poupa, 2024).

Emissions of PCDD/Fs are expressed in grams of Toxic Equivalent (**g TEQ**), representing the overall toxicity of a mixture of emitted compounds. The TEQ is a weighted measure based on the toxicity of each PCDD/F congener relative to the most toxic one. Each compound is assigned a Toxic Equivalency Factor (TEF), which reflects its toxicity compared with the most toxic congener, assigned a TEF of 1. This approach allows complex mixtures to be represented as a single value of overall toxicity.

Quality information

6. Strengths and weaknesses:

Strength: National emissions data are submitted annually, quality checked, and stored at a specialised centre.

Weakness: The data contain gaps in the time series of national emissions, uncertainties in the reported figures, lack of gridded emissions, and incomplete sectoral distribution.

7. Uncertainty:

The evaluation of emission uncertainties is conducted by national experts from each country based on the methodology outlined in the EMEP/EEA Guidebook (EEA, 2019). This methodology accounts for

uncertainties in both activity data and the emission factors applied to each emission sector. It is important to note that the uncertainties associated with emission factors are much higher than those for activity data. For POPs, the guidebook suggests a default emission factor uncertainty that exceeds 100%. Additionally, the estimates of uncertainties typically do not account for possible data incompleteness.

Among the HELCOM countries, the level of uncertainty in official data on PAH or PCDD/Fs emissions was reported by Denmark, Estonia, Finland, Latvia, Poland and Sweden. The uncertainties in reported PCDD/Fs emissions by HELCOM Contracting Parties, expressed as a percentage relative to the mean emission value, are presented in Table 2. No uncertainty estimates are available for Germany, Lithuania and Russia.

Table 2. Uncertainty estimates for PCDD/Fs emissions reported by HELCOM Contracting Parties.

Country	Uncertainty
Denmark	385%
Estonia	124%
Finland	309%
Germany	n/a (*)
Latvia	31%
Lithuania	n/a
Poland	50%
Russia	n/a
Sweden	179%
Austria	98%
Belgium	326%
Croatia	341%
Cyprus	75%
France	35%
Slovakia	87%
UK	50%

(*) Not available

8. Further work required:

Further work is needed to refine national inventories of PCDD/Fs emissions, reduce uncertainties, fill gaps in emission trends, and improve the spatial distribution of emissions. Additionally, further studies to evaluate PCDD/Fs releases into the atmosphere from natural and secondary emission sources are important for assessing PCDD/Fs pollution levels.

References

EEA [2019]. EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. EEA Report No 13/2019.

Poupa S. [2024] Methodologies applied to the CEIP GNFR gap-filling 2024. Part II: Heavy Metals (Cd, Hg, Pb) and Persistent Organic Pollutants (Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3- cd)pyrene, Total polycyclic aromatic hydrocarbons, Dioxin and Furan, Hexachlorobenzene, Polychlorinated biphenyls) of the year 2022. Technical Report CEIP 02/2024 (<https://www.ceip.at/ceip-reports/ceip-reports-2024>).