Atmospheric deposition of PCDD/Fs on the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2023

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Key message

Levels of annual total atmospheric deposition of PCDD/Fs to the Baltic Sea have decreased in period from 1990 to 2021 by 36%, although the decrease was higher during the period 1990-1996 comparing to the subsequent period 1997-2021.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This BSEFS shows the levels and trends in PCDD/F atmospheric deposition to the Baltic Sea. The deposition of PCDD/Fs represents the pressure of the emission sources on the Baltic Sea aquatic environment as described in the BSEFS "Atmospheric emissions of PCDD/Fs in the Baltic Sea region".

Policy relevance and policy reference

The updated Baltic Sea Action Plan states the ecological objectives that concentrations of hazardous substances in the environment are to be close to background values for naturally occurring substances. HELCOM Recommendation 31E/1 identifies the list of regional priority substances for the Baltic Sea.

The relevant policy to the control of emissions of PCDD/Fs to the atmosphere on European scale is set in the framework of UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). According to the CLRTAP Protocol on Persistent Organic Pollutants (1998), the emissions of PCDD/Fs must be reduced below the emission levels in 1990.

For EU member states the policy frame is set by the EU IED Directive, whereas for the Russian Federation the corresponding policy framework is embraced by the Russian Federal Act on the environmental protection and the Act on protection of atmospheric air.

Assessment

In order to assess long-term changes of PCDD/F atmospheric input to the Baltic Sea, model simulations were carried out based on officially reported emission data. Model estimates of regional scale PCDD/F pollution levels show generally satisfactory agreement with observed pollution levels.

Airborne input of PCDD/Fs to the Baltic Sea has decreased by 36% in the period from 1990 to 2021 (Figure 1, Table 1). The strongest decline is estimated for the Western Baltic sub-basin (56%), while the lowest decline is obtained for the Bothnian Bay sub-basin (11%). An increase of deposition is estimated for the Gulf of Riga sub-basin (8%).

The decrease of PCDD/F deposition to the Baltic Sea was stronger in the period 1990-1996 comparing to subsequent period 1997-2021. Trends of deposition fluxes for both periods were analysed using Mann-Kendall test methodology [*Gilbert*, 1987; *Connor et al*., 2012]. In the period from 1990 to 1996, stronger decline is estimated with the mean annual rate of deposition decline about 8 g TEQ per year with confidence factor >99%. The subsequent period of time 1997-2021 is characterised by less intensive mean annual decline rate of about 1 g TEQ per year with confidence factor >99%. The values of the confidence factors indicates that the trends for the both parts of the assessment period are significant. Reduction of atmospheric input of PCDD/Fs to the Baltic Sea is connected with the realization of various abatement measures, which took place in the HELCOM countries as well as other EMEP countries.

Higher decline in PCDD/F deposition (36%) comparing to the decline of PCDD/F emissions in HELCOM countries (27%) is explained by the use of expert estimates of PCDD/F emissions from Russia. Data for Russia were available for only one year and were extrapolated for other years of the period 1990-2021. Contribution of Russian sources to deposition over the Baltic Sea is relatively small comparing to contributions of other HELCOM countries and does not have noticeable effect on temporal changes of PCDD/F deposition to the Baltic Sea.

The highest total annual PCDD/F deposition fluxes over the Baltic Sea in 2021 are estimated for the Sound and the Western Baltic sub-basins (Figures 2, 3). The lowest deposition flux is obtained for the Bothnian Sea sub-basin. Annual emissions of HELCOM countries in 2021 contributed to PCDD/F deposition over the Baltic Sea about 22% (Table 2), with the largest shares made by Russia and Poland (Figure 4).

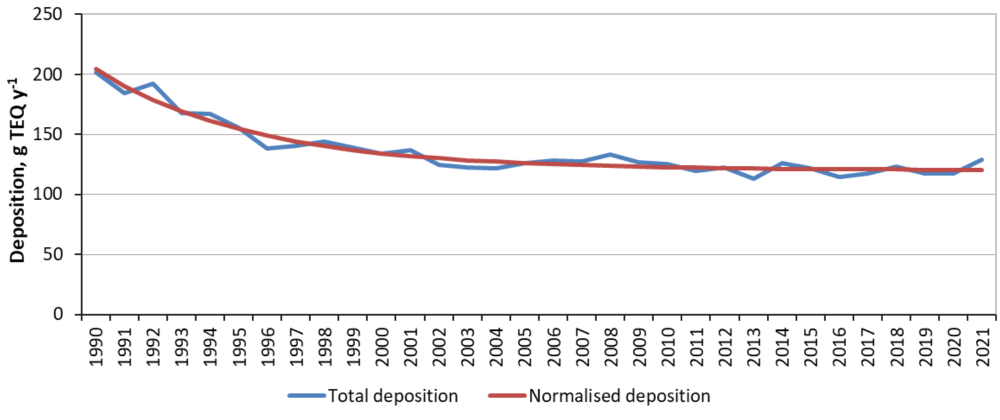

Figure 1. Long-term changes of total annual modelled atmospheric deposition (blue line) and estimates of normalized deposition (red line) of PCDD/Fs to the Baltic Sea for the period 1990-2021, (g TEQ y^{-1}). Normalized depositions were obtained using the methodology described below in the metadata section 5.

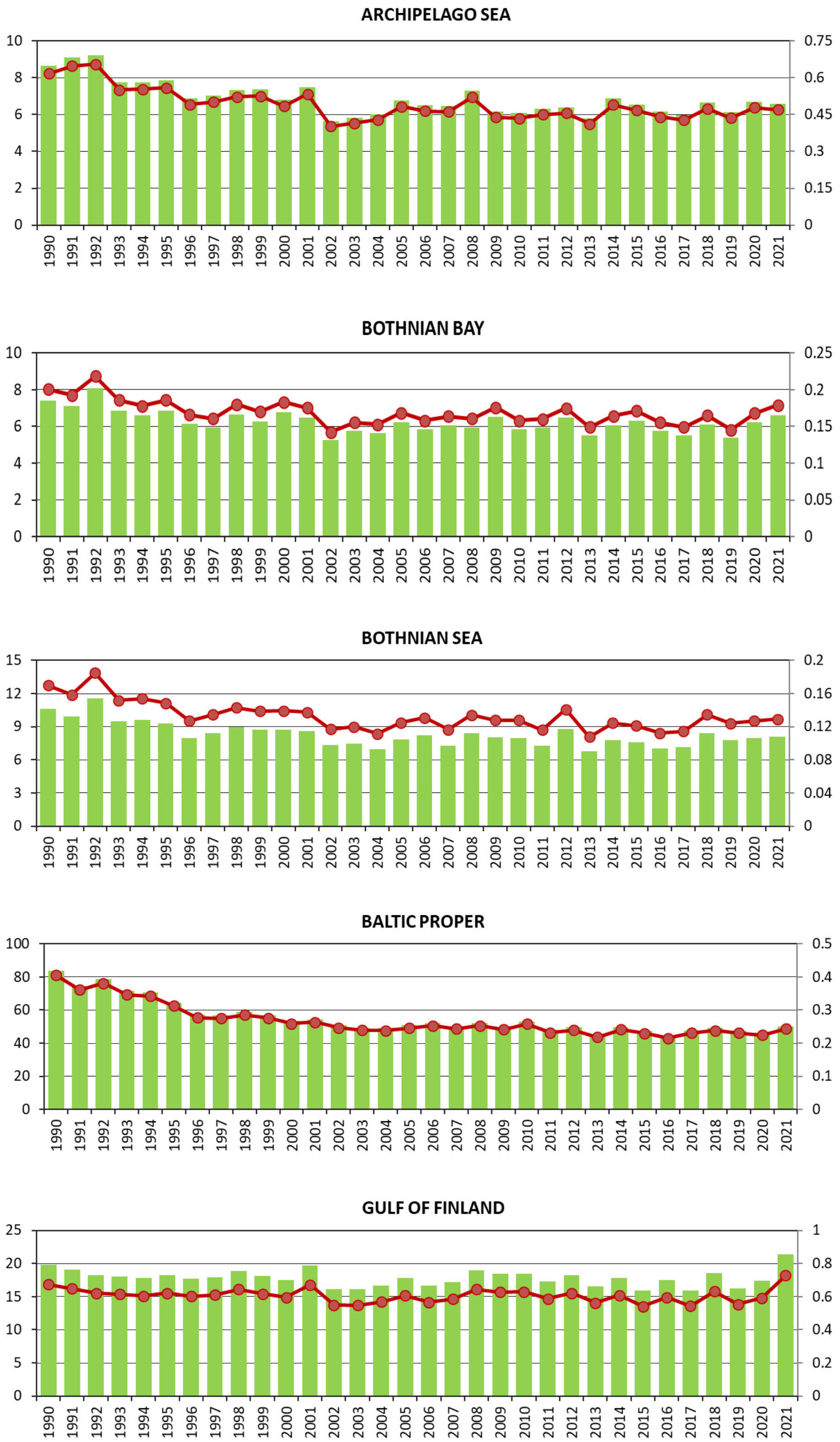

Figure 2. Time-series of computed total annual atmospheric deposition of PCDD/Fs to nine sub-basins of the Baltic Sea for the period 1990-2021 in g TEQ y^{-1} as green bars (left axis) and total deposition fluxes in mg TEQ km^{-2} y^{-1} as red lines (right axis).

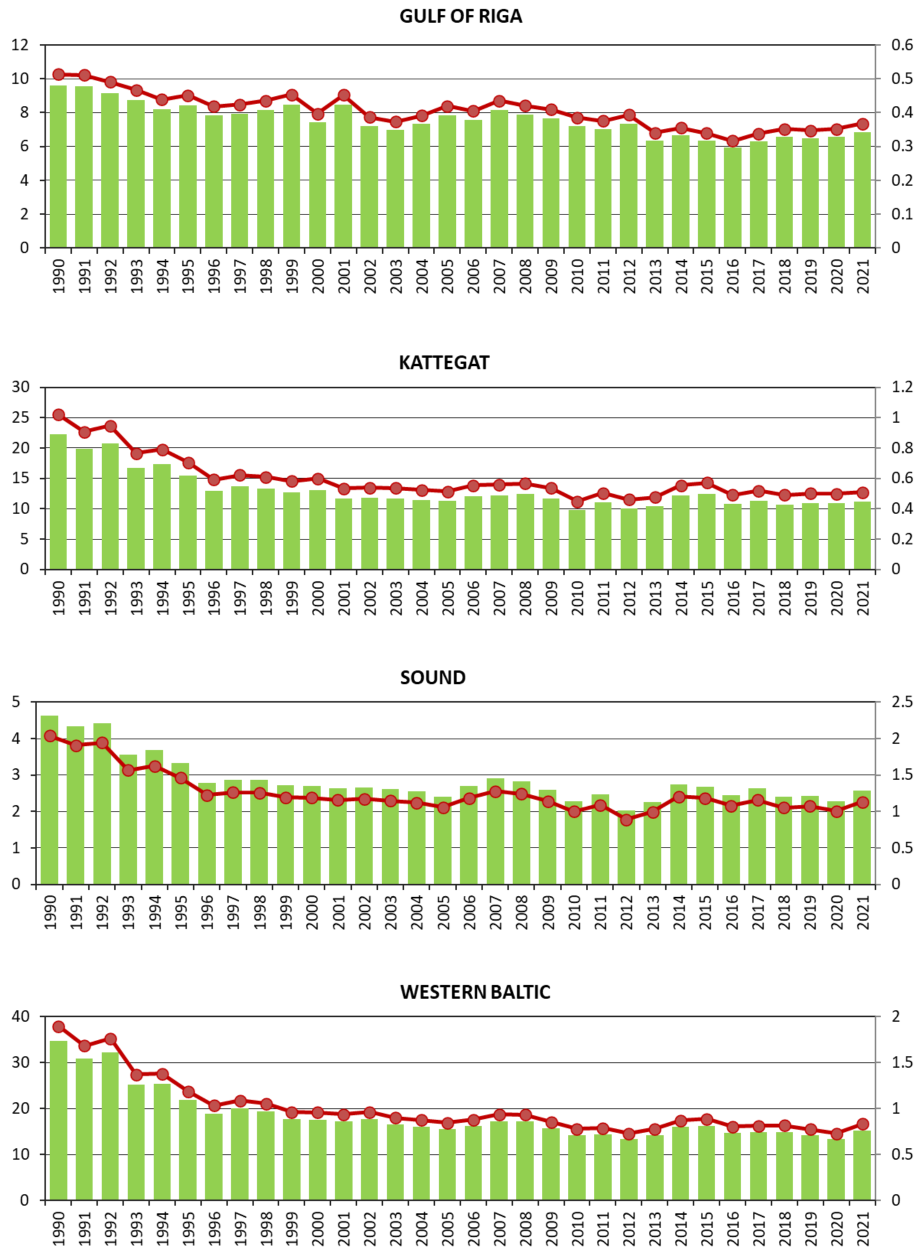

Figure 2. (continued). Time-series of computed total annual atmospheric deposition of PCDD/Fs to nine sub-basins of the Baltic Sea for the period 1990-2021 in g TEQ y^{-1} as green bars (left axis) and total deposition fluxes in mg TEQ km^{-2} y^{-1} as red lines (right axis).

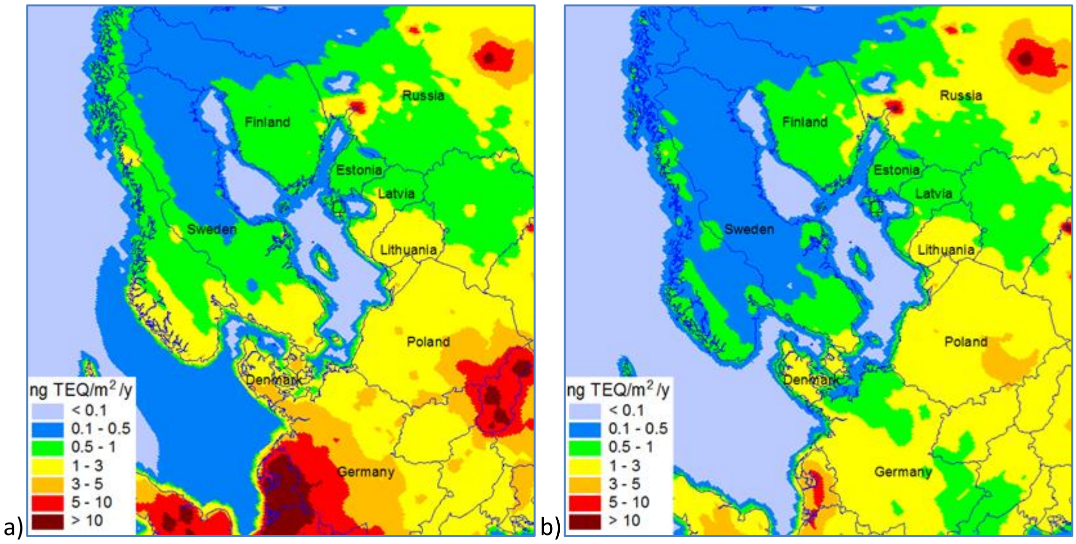

Figure 3. Spatial distribution of modelled annual total deposition fluxes of PCDD/Fs in the Baltic Sea region for 1990 (a) and 2021 (b), ng TEQ m^{-2} y^{-1}.

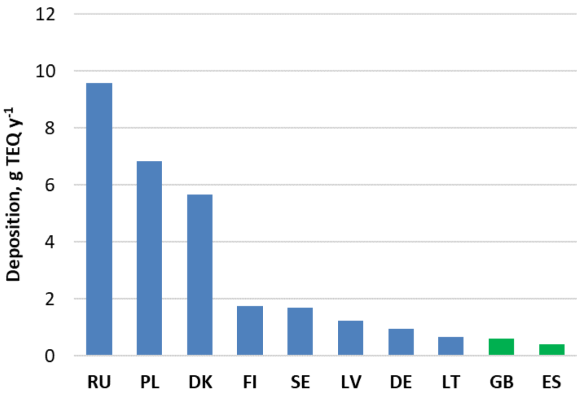

Figure 4. Ten countries with the highest contribution to annual total deposition of PCDD/Fs to the Baltic Sea estimated for 2021, g TEQ y^{-1}. Green bars indicate depositions from non-HELCOM countries.

Data

Numerical data on computed PCDD/F depositions to the Baltic Sea are given in the following tables.

Table 1. Computed total annual deposition of PCDD/Fs to nine Baltic Sea sub-basins, the whole Baltic Sea (BAS) and normalized deposition* to the Baltic Sea (Norm) for the period 1990-2021. Units: g TEQ y^{-1}.

	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS	Norm
1990	8.65	7.41	10.64	83.7	19.8	9.59	22.3	4.63	34.8	201.5	204
1991	9.10	7.12	9.92	74.6	19.1	9.55	19.8	4.34	30.9	184.4	191
1992	9.20	8.08	11.58	78.6	18.3	9.17	20.7	4.42	32.3	192.4	179
1993	7.73	6.87	9.50	71.6	18.0	8.74	16.8	3.56	25.2	168.0	169
1994	7.76	6.58	9.63	70.7	17.8	8.20	17.3	3.69	25.3	166.9	161
1995	7.85	6.86	9.30	64.6	18.2	8.43	15.4	3.32	21.8	155.8	155
1996	6.89	6.12	7.97	57.2	17.7	7.82	12.9	2.79	18.9	138.4	149
1997	7.03	5.95	8.44	56.7	17.9	7.93	13.6	2.87	20.0	140.4	144
1998	7.32	6.65	8.95	58.9	18.9	8.14	13.3	2.86	19.3	144.4	140
1999	7.37	6.28	8.70	57.0	18.1	8.47	12.7	2.72	17.7	139.0	137
2000	6.80	6.77	8.72	53.5	17.5	7.43	13.1	2.70	17.5	134.1	134
2001	7.49	6.48	8.62	54.5	19.7	8.47	11.7	2.63	17.2	136.7	132
2002	5.65	5.27	7.32	50.8	16.2	7.22	11.8	2.66	17.7	124.6	130
2003	5.82	5.74	7.50	49.4	16.1	6.98	11.7	2.61	16.5	122.4	129
2004	6.02	5.64	6.97	49.1	16.7	7.32	11.5	2.55	16.0	121.8	127
2005	6.78	6.23	7.82	50.8	17.8	7.84	11.2	2.41	15.5	126.4	126
2006	6.52	5.84	8.20	52.2	16.7	7.57	12.1	2.69	16.1	127.9	125
2007	6.47	6.05	7.30	50.2	17.2	8.14	12.2	2.90	17.2	127.7	124
2008	7.31	5.93	8.41	52.2	18.9	7.87	12.4	2.82	17.1	133.0	124
2009	6.16	6.50	8.01	49.8	18.4	7.66	11.7	2.59	15.7	126.6	123
2010	6.10	5.84	8.00	53.2	18.5	7.21	9.8	2.28	14.3	125.2	123
2011	6.32	5.93	7.26	47.9	17.3	7.01	11.0	2.48	14.4	119.6	122
2012	6.40	6.46	8.82	49.5	18.3	7.35	10.1	2.02	13.4	122.3	122
2013	5.79	5.51	6.76	45.1	16.5	6.35	10.4	2.26	14.2	112.9	122
2014	6.87	6.06	7.81	49.9	17.9	6.65	12.1	2.73	16.0	126.0	121
2015	6.55	6.32	7.58	47.5	15.9	6.34	12.5	2.69	16.3	121.6	121
2016	6.18	5.75	7.05	44.4	17.5	5.93	10.8	2.45	14.7	114.8	121
2017	5.99	5.51	7.18	47.7	15.9	6.32	11.4	2.63	14.9	117.5	121
2018	6.66	6.10	8.43	49.2	18.6	6.57	10.7	2.40	14.9	123.5	121
2019	6.11	5.37	7.77	47.6	16.3	6.48	11.0	2.44	14.2	117.2	121
2020	6.71	6.22	7.95	46.4	17.4	6.57	10.9	2.28	13.3	117.7	121
2021	6.59	6.62	8.10	50.2	21.4	6.86	11.1	2.57	15.3	128.7	120

* - normalized depositions were obtained using the methodology described below in the metadata section 5.

Table 2. Computed contributions by country to annual total deposition of PCDD/Fs to nine Baltic Sea sub-basins for the year 2021. Units: g TEQ y^{-1}. (*HELCOM*: contribution of anthropogenic sources of HELCOM countries; *EMEP*: contribution of anthropogenic sources in other EMEP countries; *Other*: contributions of secondary and remote non-EMEP emission sources).

Country	**ARC**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**KAT**	**SOU**	**WEB**	**BAS**
DK	2.43E-02	1.01E-02	2.79E-02	1.12E+00	2.04E-02	2.66E-02	1.72E+00	5.06E-01	2.23E+00	5.68E+00
EE	1.22E-02	6.74E-03	9.58E-03	5.98E-02	1.60E-01	6.97E-02	1.58E-03	2.07E-04	1.63E-03	3.22E-01
FI	3.09E-02	2.15E-02	4.75E-02	8.60E-01	2.80E-02	3.44E-02	1.35E-01	3.08E-02	5.61E-01	1.75E+00
DE	9.74E-02	3.64E-01	1.17E-01	7.24E-02	2.84E-01	2.40E-02	3.11E-03	2.97E-04	2.75E-03	9.65E-01
LV	3.22E-02	8.94E-03	2.21E-02	3.31E-01	5.55E-02	7.92E-01	3.07E-03	6.18E-04	4.73E-03	1.25E+00
LT	2.76E-02	9.83E-03	2.49E-02	4.54E-01	3.62E-02	1.14E-01	5.52E-03	1.28E-03	8.46E-03	6.82E-01
PL	1.87E-01	8.63E-02	2.27E-01	5.57E+00	1.59E-01	2.57E-01	1.42E-01	3.38E-02	1.86E-01	6.84E+00
RU	2.16E-01	2.15E-01	2.68E-01	2.03E+00	6.39E+00	3.53E-01	5.05E-02	6.62E-03	4.96E-02	9.59E+00
SE	9.51E-02	1.65E-01	2.59E-01	7.98E-01	4.35E-02	4.78E-02	1.84E-01	4.90E-02	5.43E-02	1.70E+00
AL	2.75E-04	2.43E-04	4.20E-04	2.54E-03	3.81E-04	3.29E-04	1.23E-04	1.76E-05	1.15E-04	4.45E-03
AM	7.01E-05	7.95E-05	1.25E-04	4.59E-04	9.38E-05	8.39E-05	2.41E-05	3.23E-06	2.32E-05	9.62E-04
AT	5.23E-03	5.94E-03	9.37E-03	5.34E-02	4.95E-03	4.88E-03	5.79E-03	9.19E-04	6.67E-03	9.71E-02
AZ	1.47E-04	1.87E-04	2.54E-04	7.19E-04	2.23E-04	1.59E-04	3.54E-05	3.89E-06	3.05E-05	1.76E-03
BA	2.56E-03	2.99E-03	4.13E-03	2.36E-02	3.60E-03	2.93E-03	1.20E-03	2.05E-04	1.26E-03	4.25E-02
BE	4.63E-03	3.54E-03	7.76E-03	7.02E-02	4.26E-03	4.37E-03	2.39E-02	3.32E-03	3.97E-02	1.62E-01
BG	2.11E-03	1.75E-03	3.33E-03	1.38E-02	3.23E-03	2.39E-03	8.27E-04	1.12E-04	8.40E-04	2.84E-02
BY	1.11E-02	7.77E-03	1.50E-02	8.74E-02	2.80E-02	2.46E-02	3.22E-03	5.76E-04	3.60E-03	1.81E-01
CH	1.08E-03	1.82E-03	2.72E-03	1.27E-02	1.18E-03	1.00E-03	2.38E-03	3.09E-04	3.49E-03	2.67E-02
CY	6.31E-06	7.05E-06	1.07E-05	3.20E-05	1.03E-05	7.79E-06	1.78E-06	2.20E-07	1.57E-06	7.78E-05
CZ	5.90E-03	4.55E-03	9.03E-03	8.86E-02	5.09E-03	7.33E-03	7.05E-03	1.31E-03	9.64E-03	1.38E-01
ES	1.94E-02	3.71E-02	5.43E-02	1.73E-01	2.48E-02	1.82E-02	4.80E-02	5.43E-03	4.66E-02	4.27E-01
FR	8.89E-03	1.15E-02	1.84E-02	1.14E-01	9.95E-03	9.00E-03	3.68E-02	4.44E-03	4.97E-02	2.63E-01
GB	2.00E-02	1.34E-02	3.46E-02	2.56E-01	1.91E-02	1.84E-02	1.18E-01	1.26E-02	1.34E-01	6.27E-01
GE	3.48E-04	3.62E-04	6.18E-04	2.85E-03	5.00E-04	4.46E-04	1.51E-04	2.23E-05	1.51E-04	5.44E-03
GR	6.05E-04	5.44E-04	9.87E-04	4.06E-03	9.30E-04	7.03E-04	2.35E-04	3.20E-05	2.32E-04	8.33E-03
HR	1.76E-03	2.25E-03	2.93E-03	1.32E-02	2.19E-03	1.79E-03	8.15E-04	1.48E-04	8.74E-04	2.60E-02
HU	8.06E-03	8.19E-03	1.35E-02	6.18E-02	8.99E-03	8.59E-03	3.64E-03	6.61E-04	3.75E-03	1.17E-01
IE	1.24E-03	1.02E-03	2.54E-03	1.37E-02	1.19E-03	1.10E-03	5.36E-03	5.72E-04	5.43E-03	3.22E-02
IS	9.27E-05	1.22E-04	1.69E-04	5.18E-04	1.01E-04	7.43E-05	1.56E-04	1.71E-05	1.63E-04	1.41E-03
IT	1.05E-02	1.64E-02	2.07E-02	9.15E-02	1.49E-02	1.13E-02	9.43E-03	1.32E-03	9.98E-03	1.86E-01
KY	1.06E-04	9.66E-05	1.90E-04	3.92E-04	6.84E-05	5.84E-05	3.03E-05	2.67E-06	3.41E-05	9.80E-04
KZ	1.01E-02	1.32E-02	1.76E-02	4.16E-02	1.25E-02	8.10E-03	2.45E-03	2.42E-04	2.67E-03	1.09E-01
LI	3.85E-06	6.35E-06	9.21E-06	4.47E-05	3.92E-06	3.37E-06	7.96E-06	1.09E-06	1.26E-05	9.31E-05
LU	2.35E-04	2.54E-04	4.57E-04	3.73E-03	2.47E-04	2.60E-04	8.37E-04	1.26E-04	1.48E-03	7.63E-03
MC	2.23E-05	4.38E-05	5.65E-05	2.03E-04	3.28E-05	2.42E-05	3.41E-05	4.35E-06	3.69E-05	4.58E-04
MD	6.15E-03	5.00E-03	9.42E-03	4.02E-02	9.04E-03	8.40E-03	2.38E-03	3.80E-04	2.63E-03	8.36E-02
ME	1.15E-05	1.06E-05	1.75E-05	1.09E-04	1.58E-05	1.34E-05	5.86E-06	8.60E-07	6.02E-06	1.90E-04
MK	3.82E-04	2.76E-04	5.55E-04	3.07E-03	4.93E-04	4.18E-04	1.61E-04	2.10E-05	1.55E-04	5.53E-03
MT	4.17E-06	5.31E-06	8.29E-06	3.52E-05	6.75E-06	5.36E-06	2.77E-06	3.63E-07	2.46E-06	7.07E-05
NL	7.69E-03	4.92E-03	1.22E-02	1.32E-01	7.22E-03	7.76E-03	4.59E-02	6.50E-03	8.53E-02	3.09E-01
NO	1.26E-02	9.85E-03	2.34E-02	7.69E-02	1.04E-02	9.12E-03	6.33E-02	3.57E-03	2.92E-02	2.38E-01
PT	1.23E-03	2.05E-03	3.38E-03	1.11E-02	1.38E-03	1.04E-03	3.23E-03	3.53E-04	2.93E-03	2.67E-02
RO	1.74E-02	1.47E-02	2.73E-02	1.25E-01	2.51E-02	2.15E-02	7.47E-03	1.10E-03	8.09E-03	2.47E-01
RS	3.99E-03	4.22E-03	6.17E-03	3.37E-02	5.46E-03	4.56E-03	1.76E-03	2.74E-04	1.81E-03	6.19E-02
SI	1.23E-03	1.56E-03	2.09E-03	9.57E-03	1.44E-03	1.14E-03	7.77E-04	1.39E-04	8.34E-04	1.88E-02
SK	6.75E-03	6.03E-03	1.10E-02	6.75E-02	7.21E-03	8.06E-03	4.48E-03	7.88E-04	4.73E-03	1.17E-01
TJ	5.75E-04	5.19E-04	1.06E-03	1.98E-03	3.47E-04	2.99E-04	1.57E-04	1.36E-05	1.71E-04	5.12E-03
TM	4.66E-04	6.28E-04	8.37E-04	1.79E-03	6.69E-04	4.30E-04	9.71E-05	9.63E-06	9.27E-05	5.02E-03
TR	2.80E-02	3.01E-02	4.91E-02	1.95E-01	4.86E-02	3.75E-02	9.61E-03	1.34E-03	1.02E-02	4.09E-01
UA	2.73E-02	2.02E-02	4.13E-02	1.98E-01	4.71E-02	4.10E-02	9.14E-03	1.38E-03	9.88E-03	3.95E-01
UZ	1.28E-03	1.41E-03	2.37E-03	4.58E-03	1.11E-03	8.32E-04	3.17E-04	2.88E-05	3.25E-04	1.23E-02
HELCOM	0.72	0.89	1.00	11.29	7.18	1.72	2.24	0.63	3.10	28.77
EMEP	0.23	0.23	0.41	2.03	0.31	0.27	0.42	0.05	0.48	4.43
Other	5.64	5.50	6.68	36.85	13.90	4.87	8.48	1.89	11.68	95.51
Total	6.59	6.62	8.10	50.18	21.39	6.86	11.14	2.57	15.26	128.7

Metadata

Technical information

1. Source:

Meteorological Synthesizing Centre East (MSC-E) of EMEP

2. Description of data:

Atmospheric depositions of PCDD/Fs to the Baltic Sea for the period from 1990 to 2021 were estimated using the latest version of GLEMOS model developed at EMEP/MSC-E (http://msceast.org/index.php/j-stuff/glemos). Annual PCDD/F emissions, officially reported by EMEP countries in 2023, were used in model computations for the years 1990-2021. These data are available from the web site of the EMEP Centre on Emission Inventories and Projections (CEIP) (http://www.ceip.at/). Detailed description of reported emission data, gap-filling methods, and expert estimates can be found in the CEIP Technical report [*Poupa*, 2022].

3. Geographical coverage:

Model predictions of PCDD/F atmospheric deposition were obtained for the European region and surrounding areas covered by the EMEP modelling domain.

4. Temporal coverage:

Time-series of annual atmospheric deposition of PCDD/Fs were estimated for the period 1990 – 2021.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budget of PCDD/F deposition to the Baltic Sea were computed using the latest version of GLEMOS model using the EMEP domain (https://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/). Model estimates describe regional scale distribution of pollution levels and source-receptor relationships.

GLEMOS modelling framework is a multi-scale multi-pollutant simulation platform developed for operational and research applications within the EMEP programme [*Tarrason and Gusev,* 2008; *Travnikov et al.,* 2009; *Jonson and Travnikov*, 2010; *Travnikov and Jonson*, 2011]. The framework allows simulations of dispersion and cycling of different classes of pollutants (e.g. heavy metals and persistent organic pollutants) in the environment with a flexible choice of the simulation domain (from global to local scale) and spatial resolution. The vertical structure consists of 20 irregular terrain-following sigma layers covering the height up to 10 hPa (ca. 30 km). Among these layers 10 lowest layers cover the first 5 km of the troposphere and height of the lowest model layer is about 75 m.

Anthropogenic emission data for modelling of PCDD/Fs have been prepared based on the gridded emissions fields provided by CEIP for the EMEP longitude-latitude grid system with spatial resolution 0.1x0.1 degree. Gridded emissions are complemented by additional emission parameters required for model runs (e. g. intra-annual variations and vertical distribution). Atmospheric concentrations of chemical reactants and particulate matter, which are required for the description of PCDD/F gas-particle partitioning and degradation, were imported from the MOZART model [*Emmons et al*., 2010]. Boundary conditions for model simulations over EMEP domain were estimated using the global scale GLEMOS model simulations [*Ilyin et al.*, 2022].

Meteorological data used in model simulations for 1990-2021 were obtained using WRF meteorological data pre-processor [*Skamarock et al*., 2008] on the basis of meteorological re-analyses data (ERA-Interim) of European Centre for Medium-Range Weather Forecasts (ECMWF).

Model assessment of atmospheric transport and deposition of PCDD/Fs is carried out on regular basis annually two years in arrears on the basis of emission data officially submitted by the Parties to LRTAP Convention.

Normalized values of PCDD/F deposition for the period 1990-2021 were obtained on the basis of results of model simulations using bi-exponential approximation [*Colette et al*., 2016].

Quality information

6. Strength and weakness:

Strength: annually updated information on atmospheric input of PCDD/Fs to the Baltic Sea and its sub-basins.

Weakness: uncertainties of officially submitted inventories of PCDD/F emissions, and of model estimates of secondary emissions from terrestrial and aquatic compartments.

7. Uncertainty:

Modelling approach, developed by the MSC-E for POPs, has been verified using regular comparisons of modelling results with measurements of the EMEP monitoring network [*Gusev et al*., 2005, 2006; *Shatalov et al.,* 2005; *Ilyin et al.*, 2023] and thoroughly reviewed at the workshop held in October, 2005 under supervision of the EMEP Task Force of Measurements and Modelling (TFMM). It was concluded that "MSC-E model is suitable for the evaluation of long-range transboundary transport and deposition of POPs in Europe" [ECE/EB.AIR/GE.1/2006/4].

8. Further work required:

Further work is required to reduce uncertainties of PCDD/F pollution model assessment including uncertainties of monitoring data, emission inventories, and modelling approach applied in the EMEP GLEMOS model.

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