Atmospheric nitrogen deposition to the Baltic Sea

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Key Message

Depositions of oxidised, reduced and total nitrogen were, respectively, 42%, 11% and 31% lower in 2016 than in 1995. There is a clear decreasing trend in normalised annual total deposition of nitrogen, which is consistent with the decreasing trend in nitrogen emissions from the HELCOM area: Compared to 1995, normalised depositions of oxidised, reduced and total nitrogen in 2016 were lower by, respectively, 38%, 16% and 29%.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This indicator shows the levels and trends in oxidised, reduced and total atmospheric nitrogen depositions to the Baltic Sea. The deposition of nitrogen compounds represents the pressure of emission sources on the Baltic Sea basin and catchment area.

Policy relevance and policy references

The HELCOM Copenhagen Ministerial Declaration of 2013 on Taking Further Action to Implement the Baltic Sea Action Plan reconfirmed the need of Reaching Good Environmental Status for a healthy Baltic Sea. The declaration includes nutrient reduction targets, and thus also concerns air-borne nitrogen input to the Baltic Sea. In particular, the Declaration welcomes the new targets on Maximum Allowed Inputs (based on revised harmonized eutrophication status targets) and agrees on revised Country Allocated Reduction Targets (CARTs), covering both pollution from land and airborne, which substitute the provisional country-wise nutrient reduction requirements of the Baltic Sea Action Plan.

On the European level the relevant policy to the control of emissions of nitrogen oxides and ammonia to the atmosphere is being taken in the framework of UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) and in the EU NEC Directive. The Executive Body of CLRTAP adopted the Protocol to Abate Acidification, Eutrophication and Ground Level Ozone in Gothenburg (Sweden) on 30 November 1999. The 1999 Protocol set emission ceilings for 2010 for four pollutants: sulphur oxides, nitrogen oxides, ammonia and Volatile Organic Compounds (VOCs). These ceilings were negotiated on the basis of scientific assessments of pollution effects and abatement options. Parties whose emissions had a more severe environmental or health impact and whose emissions were relatively cheap to reduce had to make the biggest cuts. The original 1999 Protocol was amended in 2012 to include national emission reduction commitments to be achieved in 2020 and beyond. Following the revised Gothenburg Protocol, nitrogen oxides emissions in 2020 will be reduced by between 18% and 56% in 31 countries, compared to 2005 annual emissions. The largest relative reductions will be in Denmark (56%), United Kingdom (55%) and

France (50%). Ammonia emissions will also be reduced in the same 31 countries, but by smaller percentages, 1-24%. The largest relative reductions of ammonia emissions will be in Denmark (24%), Finland (20%) and Sweden (15%). In the European Union, the revised Gothenburg Protocol is implemented by the new EU NEC Directive 2016/2284/EU which sets 2020 and 2030 emission reduction commitments for five main air pollutants, including nitrogen oxides and ammonia.

Assessment

Atmospheric deposition of oxidised and reduced nitrogen was computed with the latest version of the EMEP/MSC-W model. The latest available emission data for the HELCOM countries and all other EMEP sources have been used in the model calculations presented here. Deposition trends for the period 2000-2016 were recalculated with the new EMEP model version (rv4.17a) and in a better resolution, 0.1° lat × 0.1° lon (approximately 11 km x 5.5 km at 60°N) instead of 50 km × 50 km. The results are slightly different this year compared to trends calculated last year, but differences are not significant.

Both land-based emissions and emissions from shipping are included in these calculations and have been described in some more detail in this year's BSEFS on nitrogen emissions. As far as nitrogen oxides emissions from international shipping on the Baltic Sea are concerned, these have been provided by the Finnish Meteorological Institute (FMI). For historical shipping emissions (prior to 2015) the FMI data were scaled based on trends developed within the EU Horizon2020 project MACC-III and the ICCT Report by Olmer et al. (2017).

Calculated annual oxidised, reduced and total nitrogen depositions to the entire Baltic Sea basin in the period 1995 – 2016 are shown in **Figure 1**.

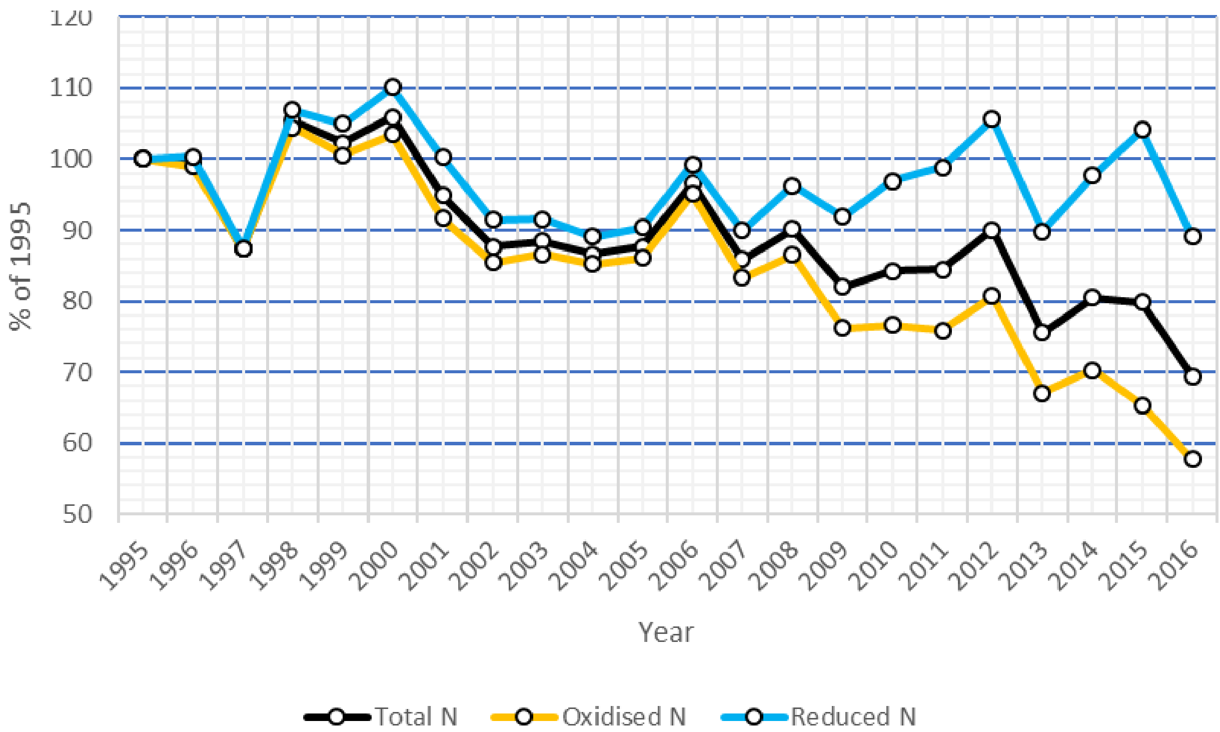

Figure 1. Atmospheric deposition of oxidised, reduced and total nitrogen to the entire Baltic Sea basin for the period 1995-2016, in percent of the respective 1995 values.

Large interannual variability in all types of nitrogen deposition to the Baltic Sea basin is seen during the considered period, but the overall trend is decreasing for all of them. Significant reductions are clearly visible in depositions of both oxidised and total nitrogen, by 42% and 31%, respectively. Annual deposition of reduced nitrogen is also 11% lower in 2016 compared to 1995.

Mainly related to inter-annual variability in meteorological conditions, annual nitrogen deposition to the Baltic Sea and its sub-basins varies significantly from one year to another in the entire period 1995 – 2016. The annual depositions of oxidised nitrogen (186 kt N), reduced nitrogen (118 kt N) and total nitrogen (304) to the Baltic Sea all peaked in the year 2000. The minima of all types of annual deposition occur in the same year, in 2016, which is the last year of the considered period. The minima of annual nitrogen deposition in the year 2016 are: 104, 96 and 199 kt N, for oxidised, reduced and total nitrogen, respectively.

To reduce the influence of inter-annual meteorological variability on annual nitrogen deposition, the so called "normalised" nitrogen deposition was calculated in the way described in Appendix D of Bartnicki et al. (2017). The calculated normalised annual deposition of total nitrogen in the period 1995-2016 is shown in Figure 2.

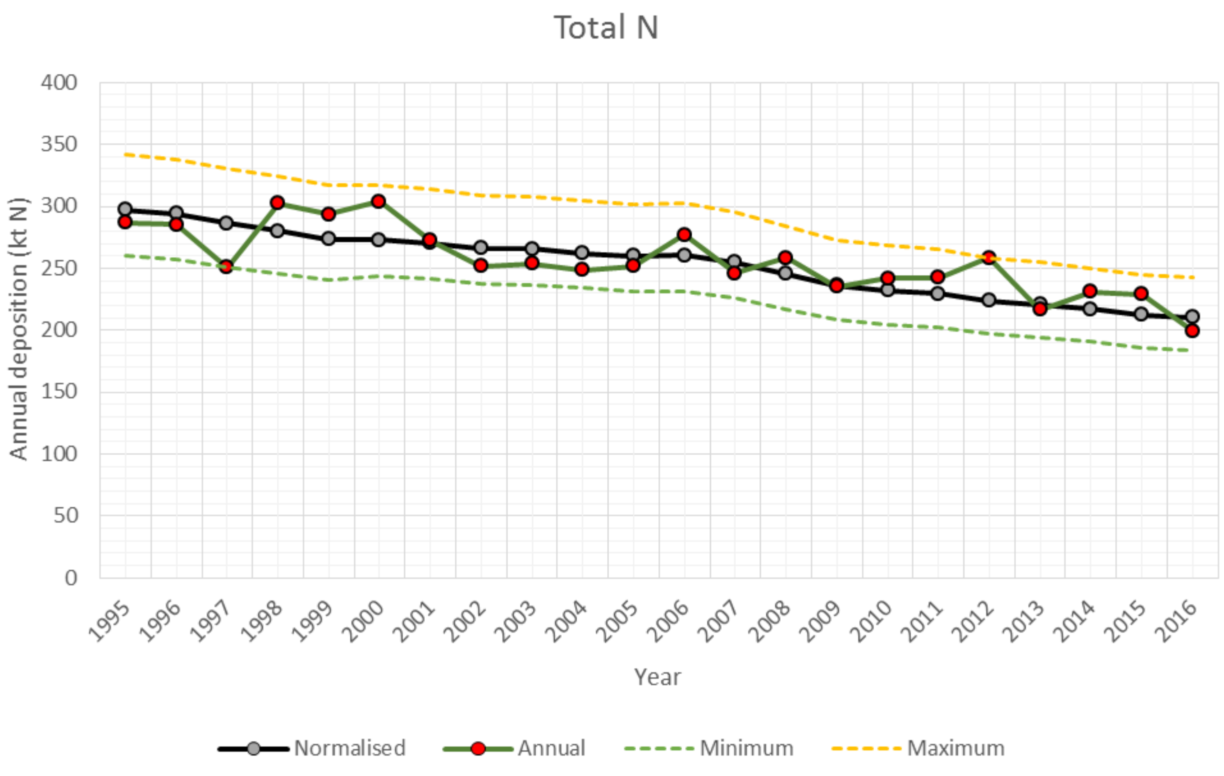

Figure 2. Normalised deposition of total nitrogen for the period 1995-2016. Minimum, maximum and actual annual values of the deposition are also shown. The minimum and maximum annual values are determined by the meteorological conditions for each particular year.

A quick inspection of Figure 2 indicates a clearly decreasing pattern in normalised annual total deposition of nitrogen which corresponds to the decreasing trend in nitrogen emissions from the HELCOM area of interest. Compared to 1995, normalised deposition of oxidised and reduced nitrogen in 2016 is lower: 38% and 16%, respectively. Normalised deposition of total nitrogen declined by 29% in the period 1995-2016.

Calculated annual total nitrogen deposition to the nine sub-basins of the Baltic Sea in the period 1995 – 2016 are presented in **Figure 3**.

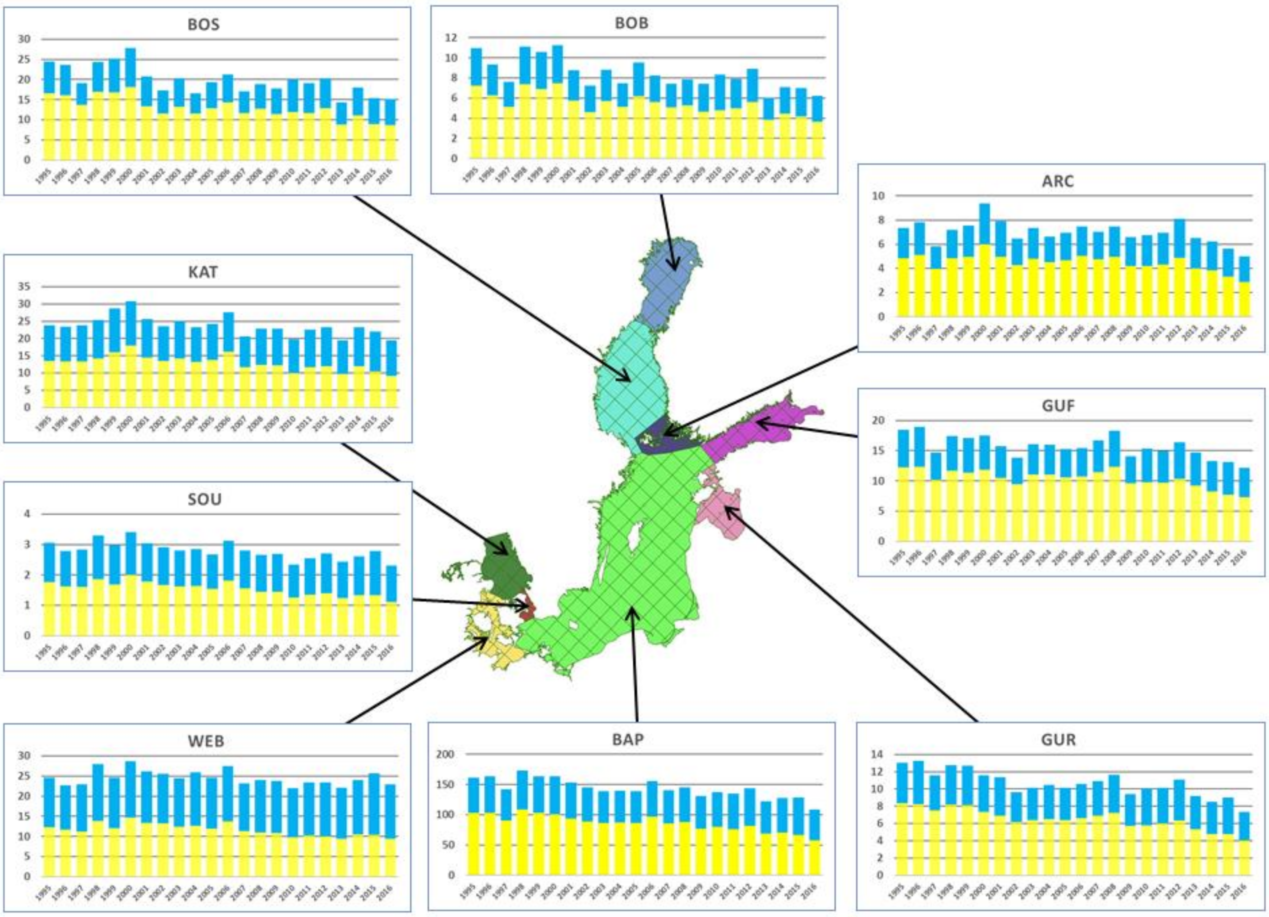

Figure 3. Atmospheric deposition of oxidised, reduced and total nitrogen to the nine sub-basins of the Baltic Sea for the period 1995 - 2016. Units: ktonnes N/year. **Note**: the scales for the sea regions are different. ARC=Archipelago Sea; BAP=Baltic Proper; BOB=Bothnian Bay; BOS=Bothnian Sea; GUF=Gulf of Finland; GUR=Gulf of Riga; KAT=Kattegat; SOU=The Sound; WEB=Western Baltic. Yellow: deposition of oxidised nitrogen, blue: deposition of reduced nitrogen.

Annual deposition of oxidised nitrogen is clearly lower (24-50%) in 2016 than in 1995 in all sub-basins. It is especially lower in the GUR (51%) and in the northern sub-basins: BOB (50%), BOS (48%). Also deposition of total nitrogen is lower in 2016 compared to 1995 in the range of 7% (WEB) to 44% (GUR). Annual deposition of reduced nitrogen is higher in 2016 than in 1995 in two out of nine sub-basins located in the western Baltic Sea: WEB (11%) and KAT (1%). It is lower in the range of 7% (SOU) to 30% (BOB, GUR) in the remaining seven sub-basins. There is a significant inter-annual variability in annual nitrogen deposition to individual sub-basins.

References

Bartnicki, J., A. Gusev, W. Aas, M. Gauss, J. E. Jonson, 2017: Atmospheric Supply of Nitrogen, Cadmium, Mercury, Lead, and PCDD/Fs to the Baltic Sea in 2015, EMEP/MSC-W Technical report 2/2017, available online at http://emep.int/publ/helcom/2017/

Data

Table 1. Annual deposition of oxidised nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2016. Units: ktonnes N per year and basin.

YEAR	Sub-basin									
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	BAS
1995	4.8	103	7.3	16.5	12.3	8.3	13.5	1.8	12.3	179.6
1996	5.1	103	6.3	16.1	12.3	8.2	13.4	1.6	11.7	178
1997	4.0	90.3	5.2	13.7	10.2	7.5	13.4	1.6	11.2	157
1998	4.9	109	7.4	16.9	11.7	8.2	14.3	1.9	13.8	188
1999	5.0	103	6.9	16.8	11.4	8.2	16.1	1.7	12.1	181
2000	6.0	101	7.5	18.1	11.9	7.3	18.0	2.0	14.7	186
2001	5.0	93.6	5.8	13.4	10.5	6.9	14.5	1.8	13.3	165
2002	4.3	89.0	4.6	11.5	9.4	6.2	13.5	1.7	13.3	154
2003	4.8	86.2	5.7	13.2	11.0	6.4	14.2	1.6	12.4	156
2004	4.5	86.9	5.1	11.5	11.1	6.5	13.2	1.6	12.6	153
2005	4.7	86.6	6.2	12.9	10.5	6.4	13.7	1.5	12.0	155
2006	5.1	96.7	5.6	14.4	10.7	6.6	16.1	1.8	13.8	171
2007	4.7	85.3	5.1	11.6	11.4	6.9	11.6	1.6	11.4	150
2008	5.0	88.1	5.3	12.7	12.3	7.2	12.3	1.4	11.0	155
2009	4.2	76.6	4.7	11.4	9.6	5.7	12.3	1.5	10.9	137
2010	4.2	80.2	4.8	11.9	9.8	5.8	10.1	1.3	9.8	138
2011	4.3	76.2	5.0	11.7	9.7	6.0	11.8	1.4	10.3	136
2012	4.9	81.6	5.6	12.8	10.3	6.3	12.0	1.4	10.1	145
2013	4.0	68.8	3.8	8.8	9.2	5.3	9.8	1.2	9.4	120
2014	3.8	70.0	4.5	11.1	8.3	4.8	11.9	1.3	10.5	126
2015	3.3	66.3	4.2	9.0	7.7	4.8	10.4	1.3	10.4	117
2016	2.9	57.4	3.7	8.7	7.3	4.1	9.2	1.1	9.4	104

Table 2. Annual deposition of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2016. Units: ktonnes N per year and basin.

YEAR	Sub-basin									
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	BAS
1995	2.5	58.3	3.7	8.0	6.2	4.7	10.3	1.3	12.3	107
1996	2.7	60.6	3.0	7.6	6.6	5.0	10.0	1.2	11.0	108
1997	1.9	52.0	2.5	5.4	4.5	4.1	10.5	1.2	11.7	93.8
1998	2.3	64.2	3.7	7.5	5.7	4.6	11.1	1.4	14.2	115
1999	2.6	61.2	3.7	8.4	5.8	4.6	12.6	1.3	12.6	113
2000	3.4	63.0	3.8	9.8	5.6	4.3	12.9	1.4	14.0	118
2001	2.9	59.3	3.0	7.4	5.3	4.4	11.1	1.3	12.9	108
2002	2.2	56.1	2.6	5.7	4.4	3.4	10.1	1.3	12.3	98.1
2003	2.5	52.8	3.1	7.0	5.0	3.7	10.8	1.2	12.1	98.2
2004	2.1	52.5	2.3	5.1	4.9	3.9	10.1	1.2	13.3	95.5
2005	2.3	52.2	3.3	6.4	4.7	3.7	10.5	1.1	12.6	97.0
2006	2.4	59.4	2.6	6.8	4.7	4.0	11.5	1.3	13.8	107
2007	2.3	55.3	2.3	5.4	5.2	4.1	9.0	1.2	11.7	96.6
2008	2.5	56.9	2.6	6.2	6.0	4.4	10.5	1.2	13.0	103
2009	2.4	54.2	2.8	6.4	4.5	3.7	10.6	1.2	12.8	98.6
2010	2.6	57.0	3.6	8.2	5.6	4.2	9.6	1.1	12.1	104
2011	2.6	58.6	2.9	7.4	5.2	4.2	10.8	1.2	13.2	106
2012	3.2	62.5	3.3	7.5	6.1	4.7	11.2	1.3	13.3	113
2013	2.5	53.3	2.2	5.5	5.5	3.9	9.7	1.2	12.7	96.4
2014	2.4	57.9	2.6	6.9	5.0	3.7	11.4	1.3	13.6	105
2015	2.3	62.1	2.8	6.4	5.4	4.2	11.7	1.5	15.3	112
2016	2.1	51.2	2.6	6.4	4.8	3.3	10.4	1.2	13.6	95.6

Table 3. Annual deposition of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2016. Units: ktonnes N per year and basin.

YEAR	Sub-basin									
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	BAS
1995	7.4	161	11.0	24.5	18.5	13.0	23.9	3.1	24.6	287
1996	7.8	164	9.3	23.6	18.9	13.3	23.5	2.8	22.7	286
1997	5.8	142	7.6	19.1	14.7	11.6	23.9	2.8	22.9	251
1998	7.2	173	11.1	24.4	17.4	12.8	25.4	3.3	28.0	302
1999	7.5	164	10.6	25.2	17.1	12.7	28.7	3.0	24.6	293
2000	9.4	164	11.3	27.9	17.5	11.6	30.9	3.4	28.7	304
2001	7.9	153	8.8	20.8	15.8	11.3	25.6	3.1	26.2	272
2002	6.5	145	7.2	17.2	13.9	9.6	23.6	2.9	25.5	252
2003	7.3	139	8.8	20.2	16.0	10.1	25.0	2.8	24.5	254
2004	6.6	139	7.5	16.6	16.0	10.5	23.3	2.9	26.0	249
2005	6.9	139	9.5	19.3	15.3	10.1	24.3	2.7	24.6	252
2006	7.5	156	8.3	21.2	15.4	10.6	27.6	3.1	27.5	277
2007	7.0	141	7.4	17.0	16.7	10.9	20.7	2.8	23.1	246
2008	7.5	145	7.8	18.9	18.3	11.7	22.9	2.7	24.0	259
2009	6.6	131	7.4	17.8	14.1	9.4	22.8	2.7	23.8	235
2010	6.7	137	8.3	20.1	15.4	10.0	19.7	2.3	21.9	242
2011	7.0	135	7.9	19.0	14.9	10.1	22.6	2.6	23.5	242
2012	8.1	144	8.9	20.3	16.4	11.1	23.3	2.7	23.4	258
2013	6.5	122	6.0	14.3	14.7	9.2	19.5	2.4	22.1	217
2014	6.2	128	7.1	18.0	13.3	8.5	23.3	2.6	24.1	231
2015	5.6	128	7.0	15.4	13.2	9.0	22.1	2.8	25.7	229
2016	5.0	109	6.3	15.1	12.1	7.3	19.6	2.3	23.0	199

Table 4. Normalized depositions of oxidised, reduced and total nitrogen to the Baltic Sea basin in the period 1995-2016. Units: ktonnes N per year.

Year	Oxidised	Reduced	Total
1995	181.0	116.5	297.2
1996	179.4	114.8	293.8
1997	172.6	113.8	286.1
1998	167.9	112.6	280.2
1999	163.2	110.3	273.2
2000	166.8	107.0	272.9
2001	164.9	106.6	270.5
2002	161.7	105.5	266.2
2003	162.4	104.3	265.6
2004	160.5	102.7	262.1
2005	158.7	102.1	259.9
2006	159.0	102.4	260.7
2007	153.7	102.0	255.0
2008	146.2	100.3	245.7
2009	137.3	99.7	236.3
2010	134.0	98.6	232.0
2011	131.1	99.0	229.5
2012	126.7	97.6	223.8
2013	123.3	97.8	220.7
2014	119.4	97.9	216.9
2015	114.2	98.2	212.2
2016	112.7	97.9	210.3

Metadata

Technical information

1. Source: EMEP/MSC-W.

2. Description of data: The atmospheric depositions of oxidised and reduced nitrogen were calculated with the latest version of EMEP/MSC-W model in Oslo. The latest available official emission data for the HELCOM countries have been used in the model computations. Emissions of two nitrogen compounds for each year of this period were officially reported to the UN ECE Secretariat by the HELCOM Contracting Parties. Missing information was estimated by experts. Both official data and expert estimates were used for modeling atmospheric transport and deposition of nitrogen compounds to the Baltic Sea - http://www.ceip.at/ .

3. Geographical coverage: Atmospheric depositions of oxidised and reduced nitrogen were computed for the entire EMEP domain, which includes Baltic Sea basin and catchment.

4. Temporal coverage: Time series of annual atmospheric depositions are available for the period 1995 – 2016.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budgets of nitrogen (oxidised, reduced and total) to the Baltic Sea basins and catchments were computed using the latest version of EMEP/MSC-W model. EMEP/MSC-W model is a multi pollutant, three-dimensional Eulerian model which takes into account processes of emission, advection, turbulent diffusion, chemical transformations, wet and dry depositions and inflow of pollutants into the model domain. Complete description of the model and its applications is available on the web http://www.emep.int.

Calculations of atmospheric transport and deposition of nitrogen compounds are performed annually two years in arrears on the basis of emission data officially submitted by Parties to CLRTAP Convention and expert estimates.

Quality information

6. Strengths and weaknesses:

Strength: annually updated information on atmospheric input of oxidised and reduced nitrogen to the Baltic Sea and its sub-basins.

Weakness: gaps and uncertainties in officially submitted by countries time series of nitrogen emissions to air increase the uncertainty of computed depositions.

7. Uncertainty:

The results of the EMEP/MSC-W model are routinely compared with available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within the accuracy of approximately 30%.

8. Further work required:

Further work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP/MSC-W model.