Atmospheric nitrogen deposition to the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2021

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Key Message

Airborne nitrogen depositions to the Baltic Sea have been calculated for the 1995 - 2019 period with the EMEP MSC-W model on 0.1° x 0.1° resolution. According to these calculations, airborne depositions of oxidised, reduced and total nitrogen were, respectively, 33%, 5% and 23% lower in 2019 than in 1995. There is a clear reduction in *normalised* depositions of nitrogen as well, which is consistent with the decrease in nitrogen emissions in the HELCOM area. Normalised depositions of oxidised, reduced and total nitrogen in 2019 were 39%, 18% and 31% lower than in 1995.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This fact sheet presents calculated changes in atmospheric deposition of oxidised, reduced and total nitrogen on the nine Baltic Sea sub-basins during the 1995-2019 period. The calculations of deposition of nitrogen compounds are based on the emission data described in the BSEFS on "Atmospheric nitrogen emissions to the air in the Baltic Sea 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 airborne nitrogen input to the Baltic Sea. The Declaration sets targets on Maximum Allowed Inputs (MAI) covering both water- and airborne inputs. These targets are maintained in the updated Baltic Sea Action Plan of 2021.

The relevant policy to the control of emissions of nitrogen oxides and ammonia to the atmosphere on a global scale is set in the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). For EU member states the policy frame is set by the EU NEC and IED Directives. For the Russian Federation the corresponding policy frame is embraced by Federal Acts on Environment Protection and the Protection of Atmospheric Air. The Gothenburg Protocol (1999, and revised in 2012) requires that nitrogen oxides emissions in 2020 should be reduced by between 18% and 56% in 31 countries with respect to 2005 annual emissions, with the largest relative reductions in Denmark (56%), the United Kingdom (55%) and France (50%). Ammonia emissions should also be reduced, but by smaller percentages (1% to 24%). The largest relative reductions of ammonia emissions should be in Denmark (24%), Finland (20%) and Sweden (15%). In the European Union, the revised Gothenburg Protocol is implemented by the EU NEC Directive 2016/2284/EU, which sets 2020 and 2030 emission reduction commitments for five main air pollutants, including nitrogen oxides and ammonia. The Gothenburg Protocol currently undergoes a review procession that will most likely result in another revision.

Assessment

Atmospheric depositions of oxidised and reduced nitrogen for the period 1995 – 2019 have been computed in 2021 with the EMEP MSC-W model version rv4.42, using the latest available gridded and gap-filled emission data for the HELCOM countries and all other EMEP sources. The calculations were performed on 0.1° × 0.1° resolution (corresponding approximately to 11 km x 5.5 km at 60°N). Both land-based emissions and emissions from shipping are included in these calculations and have been tabulated in the BSEFS on "Atmospheric nitrogen emissions to the air in the Baltic Sea area".

Calculated annual oxidised, reduced and total nitrogen depositions to the Baltic Sea basin in the period 1995 – 2019 are shown in Figure 1.

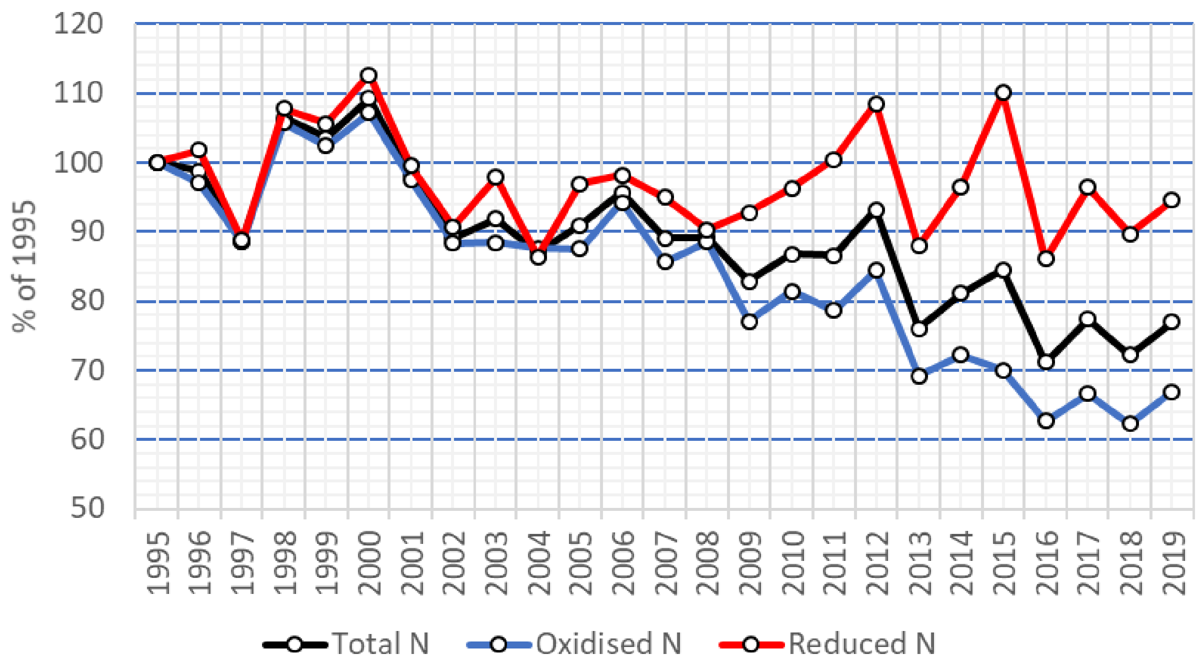


Figure 1. Atmospheric deposition of oxidised, reduced and total nitrogen to the entire Baltic Sea basin for the period 1995-2019, given as percentage of 1995 levels.

Large inter-annual variability in all types of nitrogen deposition to the Baltic Sea basin is seen during the considered period, and large reductions in depositions are calculated for both oxidised and total nitrogen in 2019, by 33% and 23%, respectively, as compared to the 1995 values. However, annual deposition of reduced nitrogen was only 5% lower in 2019 compared to 1995.

Depositions of nitrogen to the Baltic Sea peaked in the year 2000 (205, 123, and 328 ktonnes(N)/year for oxidised, reduced and total nitrogen, respectively).

Mainly related to inter-annual variability in meteorological conditions, nitrogen deposition to the Baltic Sea and its sub-basins varies significantly from year to year. Therefore, it has been common practice to "weather-normalize", depositions in order to filter out the inter-annual variability in meteorology. The method is described in Appendix D of Bartnicki et al. (2017). Basically, for each year we ask the question as to what the nitrogen deposition *would have been* with one year's emissions but with another year's meteorology. For each year, we thus calculate the depositions for all other meteorological years. Currently we have meteorological data for 25 years (1995-2019), i.e. for each year we obtain 25 different deposition values. We define the median among these as the *normalized deposition*, but in addition report the minimum and maximum values for each year (Figure 2). The changes in the normalized deposition largely reflects the changes in emissions and thus is most policy-relevant, while the deposition values in Figure 1 show the annual deposition values based on the respective year's actual meteorology.

A quick inspection of Figure 2 indicates a clearly decreasing pattern in normalised total deposition of nitrogen, corresponding to the general decrease in nitrogen emissions in the HELCOM area, which is most relevant for nitrogen deposition to the Baltic Sea. Normalised depositions of oxidised, reduced, and total nitrogen in 2019 were 39%, 18% and 31% lower than in 1995.

Figure 3 shows results from this years source-receptor analysis. The 12 most important contributors to total nitrogen deposition are shown as well as the percentage share of each contribution to the total. In addition, numbers are given for how much of each country's emission is deposited to the Baltic Sea. These numbers are sometimes referred to as 'transfer coefficients' and tend to be larger for sources that are close to the Baltic Sea or geographically located upwind of it, or both. The numbers in Figure 3 are normalized, and based on emissions of the year 2019.

Calculated nitrogen depositions to the nine sub-basins of the Baltic Sea in the period 1995 – 2019 are presented in Figure 4. For the first time this year, the coefficients for the best-fit linear trend are added, showing decreases in all cases, except for WEB which shows a slight increase for reduced nitrogen, albeit with a very small "R squared" value. R-squared is a measure of how much of the variability can be explained by the (linear trend) model. The R-squared values are written in bold font if the trend is statistically significant at the 5% level (Mann-Kendall test). It is interesting to note that the changes in reduced nitrogen depositions (if any) are smaller than the corresponding changes in reduced nitrogen emissions from HELCOM countries.

Annual depositions of oxidised nitrogen were clearly lower (by 26 to 43%) in 2019 than in 1995 in all sub-basins. The decrease is particularly large in BOB (43%), SOU and WEB (both 36%). Also the deposition of total nitrogen was lower in 2019 compared to 1995, with reductions ranging from 15% (KAT) to 37% (BOB). Annual deposition of reduced nitrogen was higher in 2019 than in 1995 in one of the nine sub-basins (KAT, 1.1%) while it was lower in the other eight sub-basins, with reductions ranging from 2.4% (BOS) to 22.9% (BOB). There is a large inter-annual variability in annual nitrogen deposition to individual sub-basins.

For convenience, the definitions of the sub-basins, along with a map of the Baltic Sea, area are given in Figure 5.

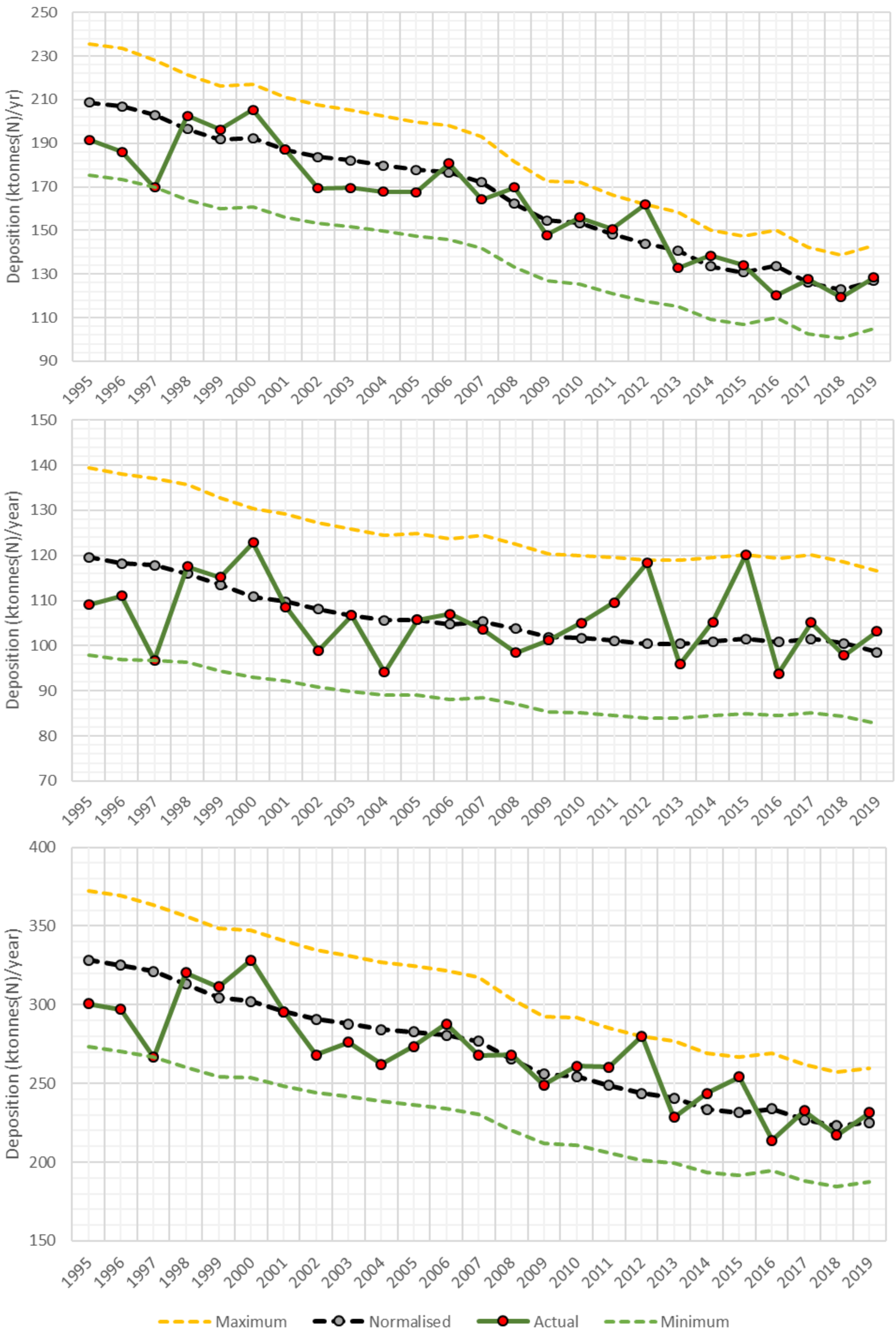
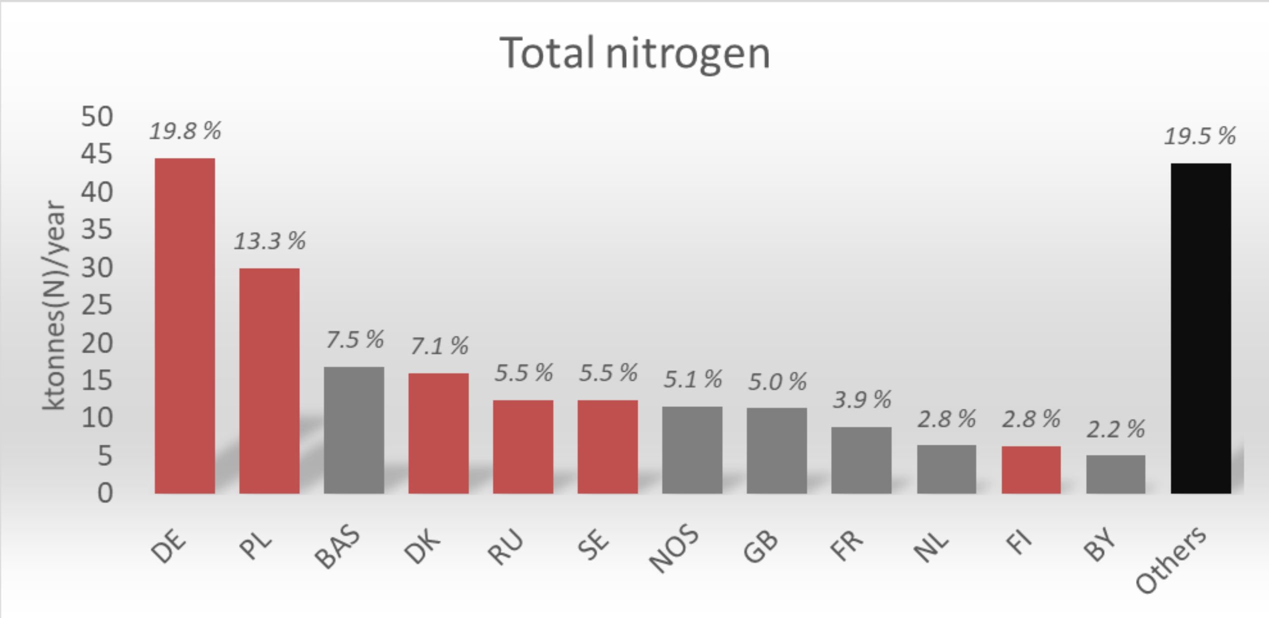
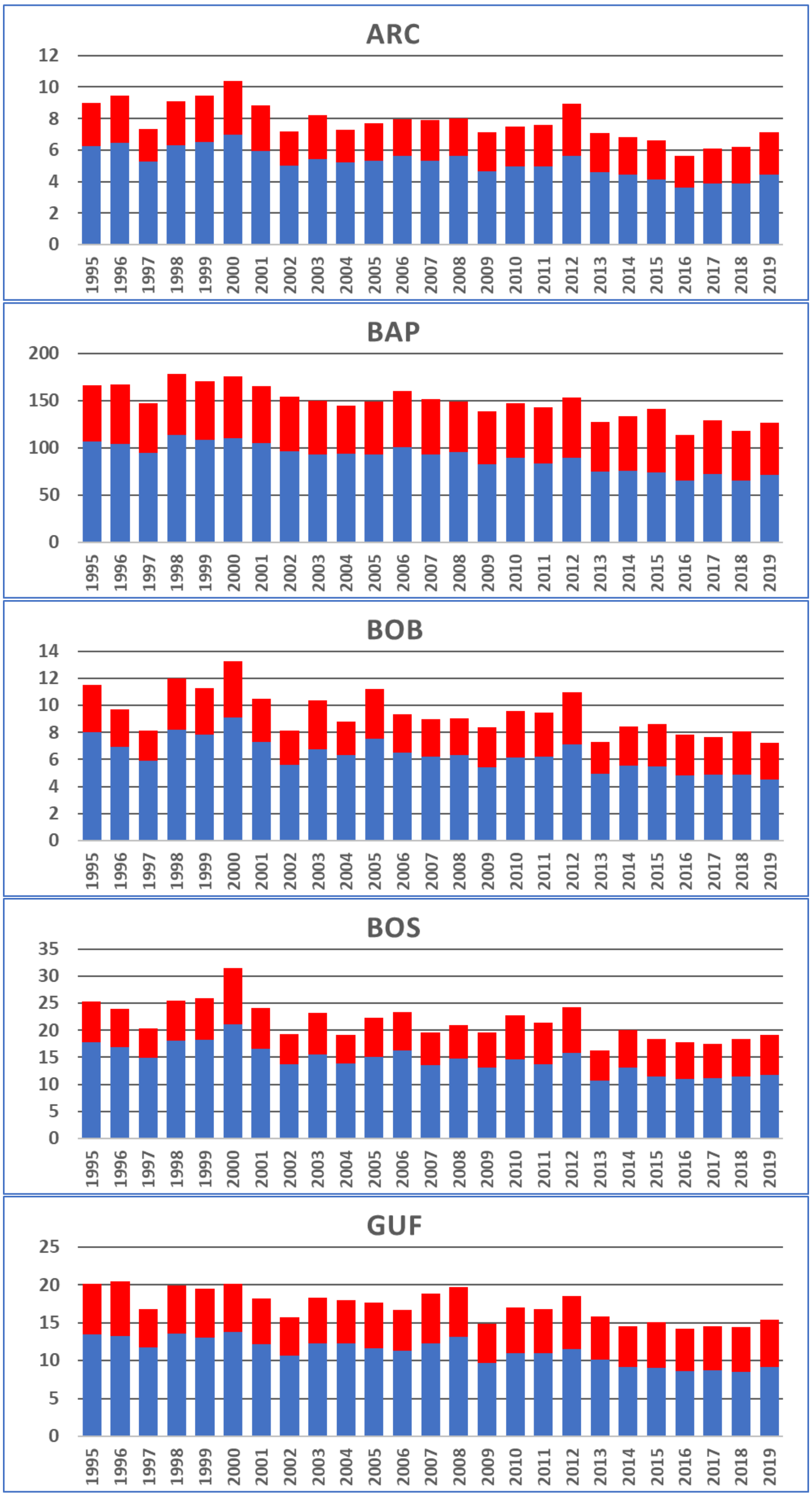


Figure 2. Normalised depositions of oxidised (top), reduced (middle) and total (bottom) nitrogen for the period 1995-2019, depicted by the black dashed line/grey dots. Unit: ktonnes(N)/year. Minimum, maximum and actual values of the depositions are also shown. The actual values correspond to the values listed in Tables 1, 2 and 3, while the normalized values are listed in Table 4. Note that the vertical scale does not start at zero, to make the variability more visible.



	DK	EE	FI	DE	LV	LT	PL	RU	SE	BAS	NOS	FR	GB
Ox-N	11%	10%	8%	5%	10%	7%	7%	0.9%	11%	16%	5%	1.8%	3.0%
Re-N	20%	16%	12%	5%	11%	9%	6%	0.4%	18%	-	-	0.9%	1.5%
Tot-N	17%	13%	10%	5%	10%	9%	6%	0.6%	15%	16%	5%	1.2%	2.3%

Figure 3. Bar chart showing the top-12 contributions to deposition of total airborne nitrogen to the Baltic Sea (NOS: North Sea Shipping; BAS: Baltic Sea shipping; GB: United Kingdom). “Others”: all countries and regions not among the indicated top-12 contributions. Red colour is used for HELCOM contracting parties. The numbers on top of each bar show the percentage share of each contribution to the total. Example: Denmark stands for 7.1% of airborne nitrogen deposition to the Baltic Sea. The table below the bar chart answers the question as to how large a percentage of each country’s domestic emissions is deposited to the Baltic Sea. Numbers are given for oxidised, reduced and total airborne nitrogen separately. Example: 10% of Estonia’s annual emission of oxidised nitrogen (NOx) is deposited to the Baltic Sea. All calculations are normalized and based on emissions of 2019.



ARC

ox-N (blue):
y = -0.10 x + 6.6, **R^2 = 0.72**

re-N (red):
y = -0.016 x + 2.8, R^2 = 0.10

BAP

ox-N (blue):
y = -1.8 x + 113, **R^2 = 0.84**

re-N (red):
y = -0.21 x + 61, R^2 = 0.10

BOB

ox-N (blue):
y = -0.12 x + 8.0, **R^2 = 0.59**

re-N (red):
y = -0.013 x + 3.3, R^2 = 0.04

BOS

ox-N (blue):
y = -0.29 x + 18, **R^2 = 0.66**

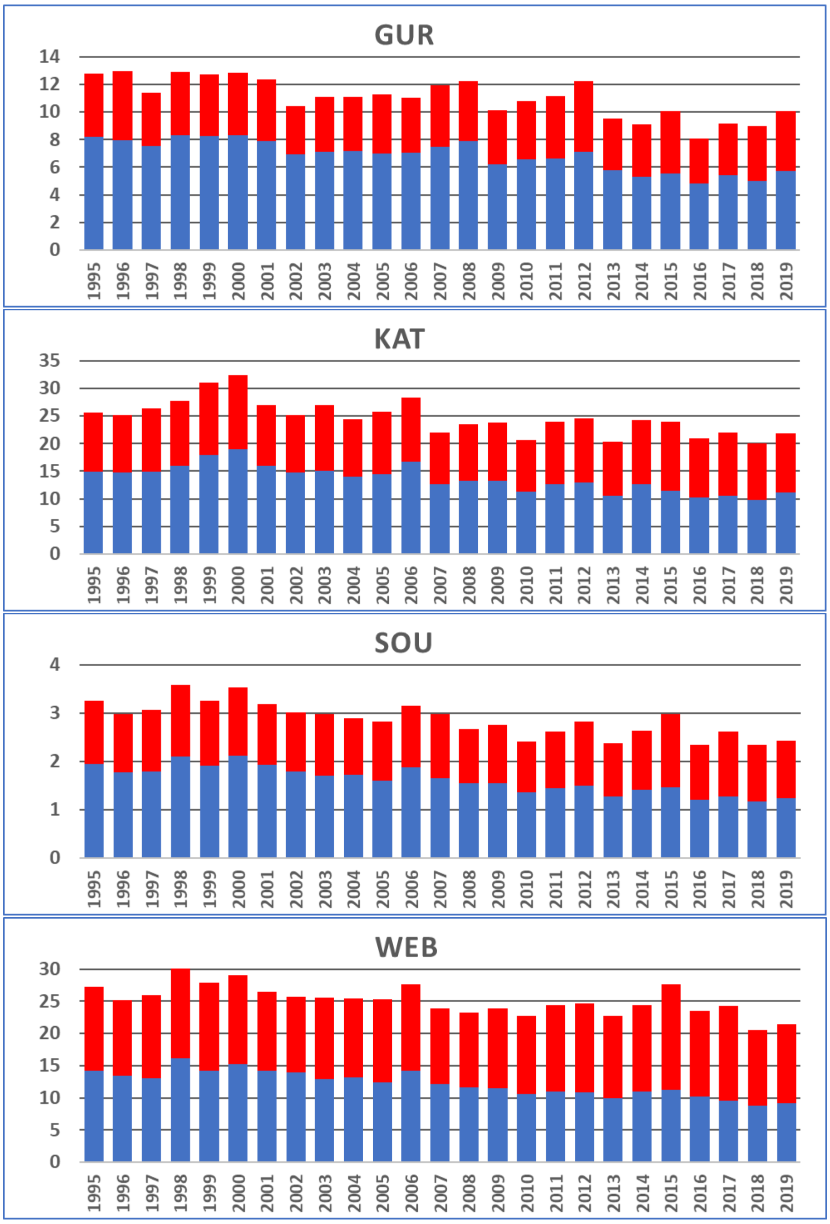
re-N (red):
y = -0.017 x + 7.3, R^2 = 0.01

GUF

ox-N (blue):
y = -0.20 x + 14, **R^2 = 0.75**

re-N (red):
y = -0.014 x + 6.2, R^2 = 0.03

Figure 4. Atmospheric deposition of oxidised nitrogen (blue) and reduced nitrogen (red) to the nine sub-basins of the Baltic Sea in the period 1995 - 2019. Unit: ktonnes(N)/year. Note that the vertical scales in the plots are different. Coefficients of the linear trend model are added to the right. An R-squared value in bold font means that the indicated trend is significant at the 5% level. The figure continues on the next page. For definition of sub-basins see Figure 5.



ox-N (blue):
$y = -0.13\,x + 8.6$, $\mathbf{R^2 = 0.79}$

re-N (red):
$y = -0.019\,x + 4.4$, $R^2 = 0.10$

ox-N (blue):
$y = -0.28\,x + 17$, $\mathbf{R^2 = 0.69}$

re-N (red):
$y = -0.027\,x + 11$, $R^2 = 0.04$

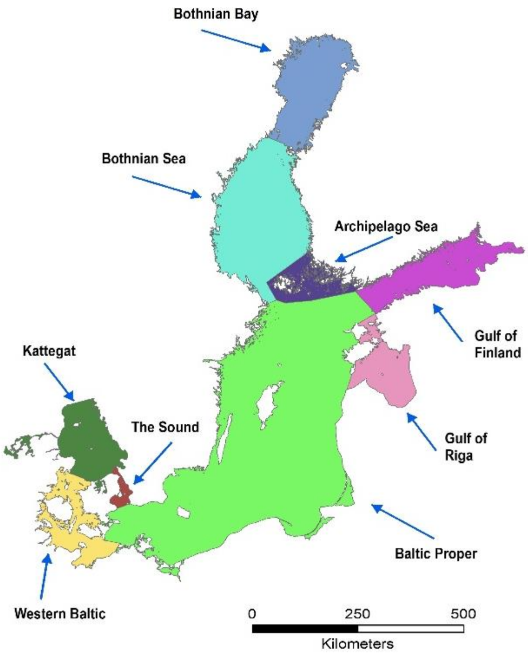
ox-N (blue):
$y = -0.03\,x + 2.1$, $\mathbf{R^2 = 0.82}$

re-N (red):
$y = -0.0045\,x + 1.3$, $R^2 = 0.08$

ox-N (blue):
$y = -0.24\,x + 15$, $\mathbf{R^2 = 0.81}$

re-N (red):
$y = 0.021\,x + 13$, $R^2 = 0.02$

Figure 4. Continued.



Sub-basin	Abbreviation	Area in km^2
Archipelago Sea	ARC	13405
Baltic Proper	BAP	209258
Bothnian Bay	BOB	36249
Bothnian Sea	BOS	65397
Gulf of Finland	GUF	29998
Gulf of Riga	GUR	18646
Kattegat	KAT	23659
The Sound	SOU	2328
Western Baltic	WEB	18647
Baltic Sea basin	**BAS**	**417587**

Figure 5. Locations of the nine sub-basins of the Baltic Sea, used for all nitrogen deposition calculations presented in this report. The figure with the sub-basins has been provided by the Baltic Nest Institute (BNI).

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/

Granier, C., Darras, S., Denier van der Gon, H., Doubalova, J., Elguindi, N., Galle, B., Gauss, M., Guevara, M., Jalkanen, J.-P., Kuenen, J., Liousse, C., Quack, B., Simpson, D., and Sindelarova, K.: The Copernicus Atmosphere Monitoring Service global and regional emissions (April 2019 version), doi:10.24380/d0bn-kx16, Link for direct download: https://atmosphere.copernicus.eu/sites/default/files/2019-06/cams_emissions_general_document_apr2019_v7.pdf.

JRC/PBL: Emission Database for Global Atmospheric Research (EDGAR), Global Emissions EDGAR v4.3.1, European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL), URL http://edgar.jrc.ec.europa.eu, 2016.

Data

Table 1. Annual deposition of oxidised nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2019. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	6.3	107	8.0	17.8	13.5	8.2	15.0	1.9	14.2	192
1996	6.5	105	6.9	16.9	13.3	7.9	14.7	1.8	13.4	186
1997	5.3	94.5	5.9	15.0	11.7	7.5	15.0	1.8	13.0	170
1998	6.3	114	8.2	18.1	13.5	8.3	16.0	2.1	16.1	203
1999	6.5	108	7.8	18.2	13.1	8.2	18.0	1.9	14.3	196
2000	7.0	110	9.1	21.1	13.8	8.3	19.0	2.1	15.3	205
2001	5.9	105	7.3	16.5	12.1	7.9	15.9	1.9	14.2	187
2002	5.0	96.8	5.6	13.6	10.7	6.9	14.8	1.8	13.9	169
2003	5.4	92.7	6.8	15.5	12.3	7.1	15.1	1.7	12.9	170
2004	5.2	94.1	6.3	13.8	12.3	7.2	14.1	1.7	13.2	168
2005	5.3	92.7	7.5	15.1	11.7	7.0	14.4	1.6	12.4	168
2006	5.6	101	6.5	16.3	11.3	7.0	16.7	1.9	14.2	181
2007	5.3	93.0	6.2	13.6	12.3	7.5	12.6	1.7	12.1	164
2008	5.6	95.3	6.4	14.8	13.2	7.9	13.3	1.5	11.6	170
2009	4.7	82.4	5.4	13.1	9.7	6.2	13.2	1.5	11.5	148
2010	5.0	89.4	6.1	14.7	11.0	6.6	11.3	1.4	10.6	156
2011	5.0	83.2	6.2	13.7	10.9	6.6	12.6	1.4	11.0	151
2012	5.6	89.4	7.1	15.8	11.5	7.1	12.9	1.5	10.9	162
2013	4.6	74.7	4.9	10.8	10.2	5.8	10.5	1.3	10.0	133
2014	4.5	75.9	5.5	13.1	9.2	5.3	12.7	1.4	11.0	138
2015	4.1	74.3	5.5	11.5	9.1	5.6	11.5	1.5	11.2	134
2016	3.6	65.5	4.9	11.1	8.6	4.8	10.2	1.2	10.2	120
2017	3.9	72.3	4.9	11.2	8.7	5.4	10.5	1.3	9.5	128
2018	3.9	65.9	4.9	11.4	8.5	5.0	9.8	1.2	8.8	119
2019	4.4	71.2	4.5	11.8	9.1	5.7	11.1	1.2	9.1	128

Table 2. Annual deposition of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2019. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	2.8	59.0	3.5	7.5	6.7	4.5	10.7	1.3	13.1	109
1996	3.0	62.6	2.8	7.1	7.2	5.0	10.4	1.2	11.8	111
1997	2.1	52.9	2.2	5.4	5.0	3.8	11.3	1.3	12.8	96.8
1998	2.8	64.6	3.8	7.4	6.3	4.6	11.7	1.5	14.9	118
1999	3.0	62.2	3.4	7.7	6.4	4.5	13.1	1.3	13.6	115
2000	3.4	65.5	4.2	10.4	6.3	4.6	13.3	1.4	13.8	123
2001	2.9	59.8	3.2	7.6	6.0	4.5	11.1	1.3	12.3	109
2002	2.2	56.9	2.5	5.6	5.0	3.5	10.3	1.2	11.7	99.0
2003	2.8	56.9	3.6	7.6	6.0	4.0	11.9	1.3	12.6	107
2004	2.1	50.8	2.5	5.4	5.7	3.9	10.4	1.2	12.2	94.2
2005	2.4	56.5	3.7	7.3	6.0	4.3	11.4	1.2	12.9	106
2006	2.4	59.3	2.8	7.0	5.3	4.0	11.6	1.3	13.4	107
2007	2.5	58.6	2.8	6.0	6.6	4.4	9.4	1.3	11.8	104
2008	2.4	53.7	2.7	6.1	6.5	4.3	10.1	1.1	11.6	98.5
2009	2.5	56.1	3.0	6.5	5.2	3.9	10.5	1.2	12.4	101
2010	2.5	58.1	3.5	8.2	6.0	4.2	9.4	1.1	12.1	105
2011	2.6	59.7	3.3	7.7	5.9	4.5	11.3	1.2	13.4	110
2012	3.3	63.8	3.9	8.5	7.0	5.1	11.6	1.3	13.7	118
2013	2.5	52.3	2.4	5.6	5.6	3.7	9.9	1.1	12.8	95.9
2014	2.4	57.8	2.9	7.0	5.3	3.8	11.5	1.2	13.3	105
2015	2.5	66.5	3.1	6.9	6.1	4.5	12.4	1.5	16.5	120
2016	2.0	48.2	3.0	6.7	5.6	3.2	10.7	1.1	13.4	93.9
2017	2.2	56.7	2.8	6.3	5.8	3.8	11.5	1.3	14.7	105
2018	2.4	52.3	3.2	7.0	6.0	4.0	10.2	1.2	11.7	97.8
2019	2.7	55.5	2.7	7.3	6.3	4.3	10.8	1.2	12.3	103

Table 3. Annual deposition of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2019. Unit: ktonnes(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	9.0	166	11.5	25.3	20.1	12.8	25.6	3.3	27.2	301
1996	9.5	167	9.7	24.0	20.4	12.9	25.1	3.0	25.2	297
1997	7.3	147	8.1	20.3	16.7	11.4	26.3	3.1	25.9	266
1998	9.1	178	12.0	25.5	19.9	12.9	27.8	3.6	31.0	320
1999	9.4	170	11.3	25.9	19.5	12.7	31.1	3.3	27.8	311
2000	10.4	175	13.3	31.5	20.1	12.8	32.3	3.5	29.1	328
2001	8.8	165	10.5	24.1	18.2	12.3	27.0	3.2	26.5	296
2002	7.2	154	8.1	19.3	15.7	10.4	25.1	3.0	25.7	268
2003	8.2	150	10.4	23.2	18.3	11.1	27.0	3.0	25.5	276
2004	7.3	145	8.8	19.2	18.0	11.1	24.4	2.9	25.4	262
2005	7.7	149	11.2	22.4	17.7	11.3	25.8	2.8	25.3	273
2006	8.0	160	9.3	23.3	16.7	11.0	28.3	3.2	27.6	288
2007	7.9	152	9.0	19.6	18.8	11.9	22.0	3.0	23.9	268
2008	8.0	149	9.0	20.9	19.7	12.2	23.5	2.7	23.3	268
2009	7.1	139	8.4	19.6	14.9	10.1	23.7	2.8	23.9	249
2010	7.5	147	9.6	22.8	17.0	10.8	20.7	2.4	22.7	261
2011	7.6	143	9.5	21.5	16.8	11.1	23.9	2.6	24.4	260
2012	8.9	153	11.0	24.3	18.5	12.2	24.6	2.8	24.6	280
2013	7.1	127	7.3	16.3	15.8	9.5	20.4	2.4	22.8	229
2014	6.8	134	8.4	20.1	14.5	9.1	24.2	2.6	24.4	244
2015	6.6	141	8.6	18.4	15.1	10.1	23.9	3.0	27.7	254
2016	5.7	114	7.8	17.8	14.2	8.1	20.9	2.3	23.5	214
2017	6.1	129	7.7	17.5	14.6	9.2	22.0	2.6	24.2	233
2018	6.2	118	8.1	18.4	14.5	9.0	20.1	2.3	20.5	217
2019	7.1	127	7.3	19.1	15.4	10.1	21.9	2.4	21.5	232

Table 4. Normalized depositions of oxidised, reduced and total nitrogen to the Baltic Sea basin in the period 1995-2019. Unit: ktonnes(N)/year. (Normalized deposition of total nitrogen may slighly differ from the sum of normalized depositions of oxidised and reduced nitrogen; this is due to the use of medians during normalization.)

Year	Oxidised Nitrogen	Reduced Nitrogen	Total Nitrogen
1995	208.8	119.6	328.4
1996	207.0	118.2	325.2
1997	203.1	117.9	321.1
1998	196.5	116.0	313.0
1999	191.8	113.5	304.6
2000	192.3	110.8	302.1
2001	187.0	109.7	295.6
2002	183.8	108.1	290.8
2003	182.1	106.7	287.8
2004	179.8	105.6	284.3
2005	177.8	105.7	282.7
2006	176.6	104.8	280.7
2007	172.1	105.3	276.8
2008	162.3	103.8	265.4
2009	154.6	101.9	255.9
2010	153.4	101.7	254.3
2011	148.3	101.1	248.8
2012	143.9	100.4	243.8
2013	140.9	100.4	240.6
2014	133.6	100.9	233.7
2015	130.7	101.5	231.4
2016	133.7	100.8	233.9
2017	126.0	101.5	227.0
2018	123.0	100.5	223.1
2019	126.8	98.5	225.1

Metadata

Technical information

1. Source: EMEP MSC-W.

2. Description of data: The atmospheric depositions of oxidised and reduced nitrogen were calculated with the EMEP MSC-W model, version rv4.42. For the 1995-1999 period, emission data based on 2019 official data submissions from the HELCOM countries were used in the model computations. For 2000 to 2019, emission data based on official submissions of 2021 were used. 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 is estimated by experts. Both official data and expert estimates were used for modeling atmospheric transport and deposition of nitrogen compounds to the Baltic Sea.

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

4. Temporal coverage: Time series of annual atmospheric depositions are available for the period 1995 – 2019.

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 EMEP MSC-W model, version rv4.42. The 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. A complete description of the model and its applications is available on the web (direct link to web page of the model: https://github.com/metno/emep-ctm)

Calculations of atmospheric transport and deposition of nitrogen compounds are performed annually on the basis of emission data officially submitted by Parties to CLRTAP Convention and expert estimates. In order to filter out inter-annual variability in meteorology, the depositions are also reported as "weather-normalized" depositions; the method for this is described in Appendix D of Bartnicki et al. (2017).

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 the officially submitted time series of nitrogen emissions to air by countries 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 an accuracy of approximately 25%.

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.