# Atmospheric nitrogen deposition to the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2023

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## Key Message

Airborne nitrogen depositions to the Baltic Sea have been calculated for the 1990 – 2021 period with the EMEP MSC-W model at 0.1° x 0.1° resolution.

According to our model calculations, *actual* airborne depositions of oxidised, reduced and total nitrogen were, respectively, 45%, 14% and 34% lower in 2021 than in the reference period 1997 – 2003. There is a clear reduction in *normalised* depositions of nitrogen as well, which is consistent with the change in nitrogen emissions in the HELCOM area. Normalised depositions of oxidised, reduced and total nitrogen in 2021 were 43%, 17% and 34% lower than in the reference period 1997 – 2003.

## 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 to the Baltic Sea and its nine sub-basins during the 1990 – 2021 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 amended in 2019) 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 has recently undergone a review process that will most likely result in a new revision.

## Assessment

Atmospheric depositions of oxidised and reduced nitrogen for the period 1990 – 2021 reported here were computed in summer 2023 with the EMEP MSC-W model version rv5.0, using the latest available gridded and gap-filled emission data for the HELCOM countries and all other EMEP sources. The calculations were performed at 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”.

Time series of oxidized, reduced and total nitrogen depositions to the Baltic Sea with respect to the reference period of 1997 – 2003 are shown in Figure 1.

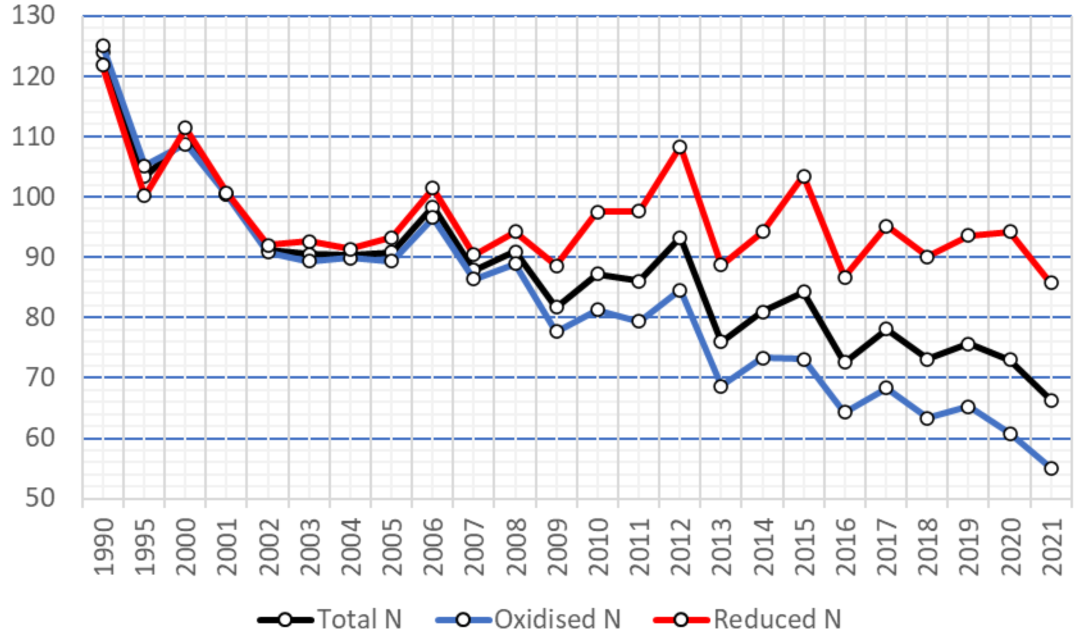


**Figure 1**. Atmospheric deposition of oxidised, reduced and total nitrogen to the entire Baltic Sea basin for the period 1990-2021, given as percentage of the average values for the 1997 – 2003 reference period.

Large interannual 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 oxidised and total nitrogen in 2021, by 45% and 34%, respectively, as compared to the reference period 1997 - 2003. However, annual deposition of *reduced* nitrogen was only 14% lower in 2021 than in the reference period 1997 - 2003.

Mainly related to interannual variability in meteorological conditions, nitrogen deposition to the Baltic Sea and its sub-basins varies strongly from year to year. Therefore, it has been common practice to ‘weather-normalize’ depositions to filter out the interannual 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 calculate the depositions for all other meteorological years by using *transfer coefficients*[1] for these years. Currently we have data on transfer coefficients for 27 years (1995-2021). In this way we can calculate 27 different deposition values for each emission year. We define the median among these values as the *normalized* deposition, but in addition report the minimum and maximum values for each year (Figure 2). The change in the normalized deposition largely reflects the changes in emissions and is thus most policy-relevant, while the deposition values in Figure 1 show the deposition values based on the respective year's *actual* meteorology, which is why we refer to them as 'actual deposition'.

An inspection of Figure 2 indicates a downward tendency in normalised total deposition of nitrogen, corresponding to the general downward tendency 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 2021 were 43%, 17% and 34% lower than in the reference period 1997 – 2003.

Figure 3 shows results from this year's 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. The numbers in Figure 3 are normalized, and based on emissions of the year 2021.

In addition, numbers are given for how much of each country's emission is deposited to the Baltic Sea (Table 1). These numbers correspond to the transfer coefficients mentioned above and tend to be larger for sources that are close to the Baltic Sea or geographically located upwind of it, or both. However, there are many factors that determine the exact magnitude of transfer coefficients, such has meteorological conditions, the chemical lifetime of the species, and the location of emission sources with respect to receptor areas. For example, *reduced* nitrogen emitted several tens of kilometers away (and upwind) from the coast will have a smaller chance of being deposited to the sea than *oxidized* nitrogen because the latter has a longer chemical lifetime. However, if the emission source is located on the coast, the difference in lifetime may not have any effect because both reduced and oxidized nitrogen will be deposited to the sea located just downwind of the emission source. Indeed, if the adjacent sea area is narrow, e.g. the Kattegat, *reduced* nitrogen emitted from a Danish source close to the coast may even have a larger chance of being deposited to the sea than oxidized nitrogen, because the latter may have a sufficiently long lifetime to get transported to Sweden.

Calculated nitrogen depositions to the nine sub-basins of the Baltic Sea in the period 1990 – 2021 are presented in Figure 4, while Table 2 lists trends that are statistically significant at the 5% level (Mann-Kendall test). Slopes of the linear regression line are calculated for the whole 32-year period, for the 1990s and for the most recent decade. Trends in oxidized nitrogen are of clearly larger magnitude than those in reduced nitrogen, when the whole period is considered. 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. During the period 2011-2021 there are no significant trends in the deposition of reduced nitrogen except in WEB.

Compared to the reference period 1997 – 2003, actual depositions of oxidised nitrogen were clearly lower in 2021 (by 41 to 49%) in all sub-basins. The change is particularly large in KAT (51%), SOU (50%) and ARC (49%). Reductions in actual depositions of reduced nitrogen range from 3% (BOS) to 24% (KAT). Consequently, the deposition of total nitrogen was lower in 2021 compared to the reference period 1997 – 2003 in all sub-basins, with reductions ranging from 29% (BOB) to 40% (ARC). There is, however, a large interannual 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, are given in Figure 5.

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[1] Transfer coefficients are a measure for how much of the emissions from one country is deposited to a given receptor area (in this case the Baltic Sea). Transfer coefficients largely depend on meteorology, the distance between the source and the receptor, but also on the chemical regime in the atmosphere.

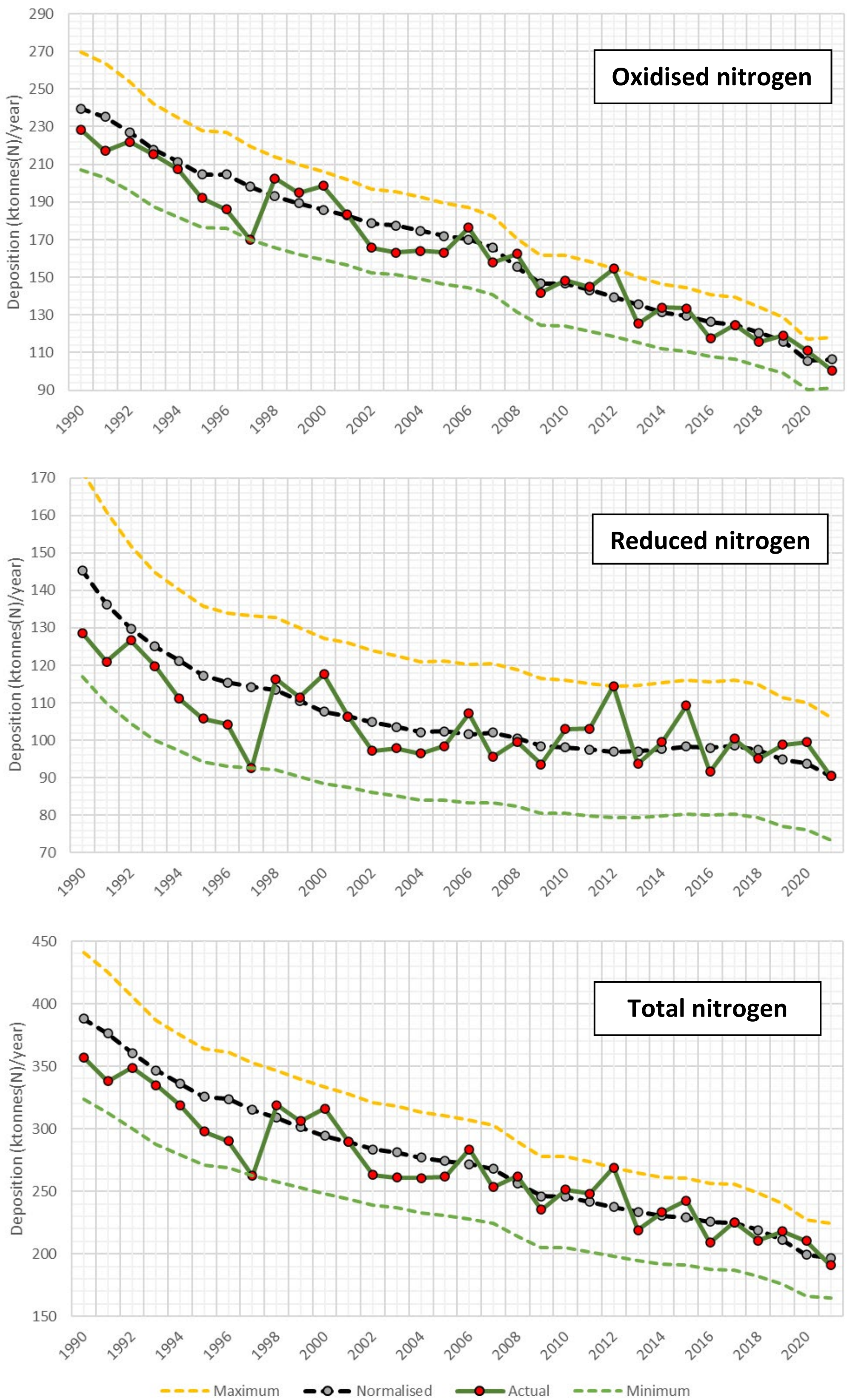



**Figure 2.** Normalised depositions of oxidised (top), reduced (middle) and total (bottom) nitrogen for the period 1990-2021, depicted by the black dashed line/grey dots. Unit: ktonnes(N)/year. Minimum, maximum and actual values of the depositions are also shown. The actual values correspond to the values listed in Tables 3, 4 and 5, while the normalized values are listed in Table 6. Note that the vertical scale does not start at zero, to make the variability more visible.

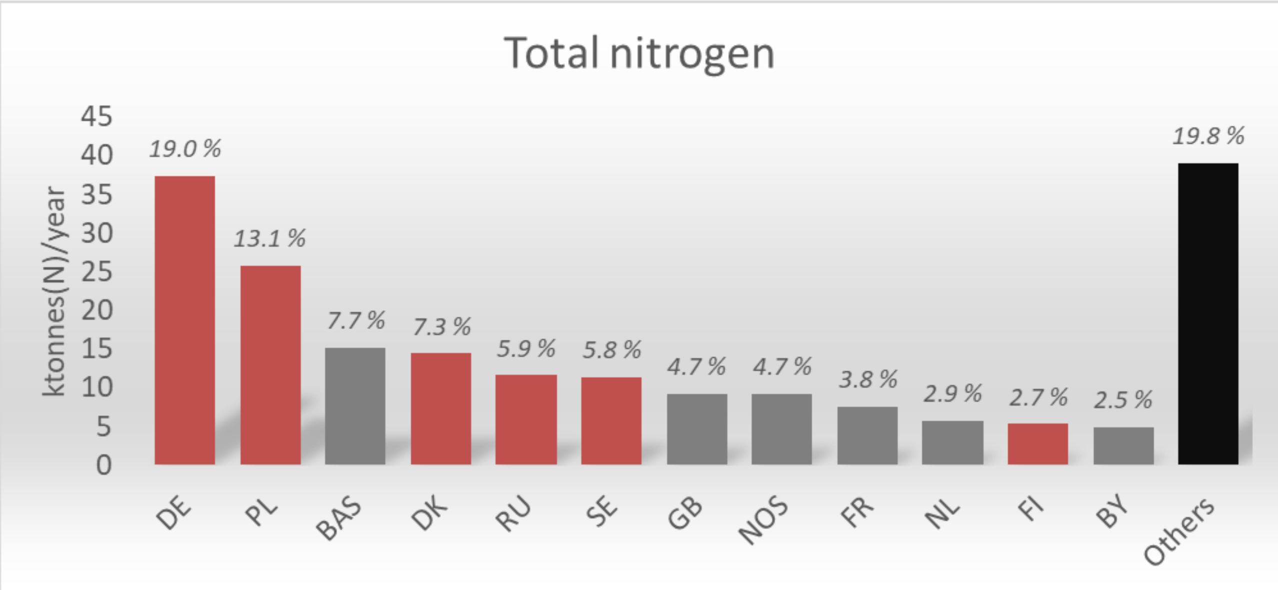



**Figure 3.** Bar chart showing the top-12 contributions to deposition of total airborne nitrogen to the Baltic Sea (NOS: North Sea Shipping; BAS: Baltic Sea shipping; GB: United Kingdom). "Others": all countries and regions that are not among the indicated top-12 contributions. Red colour is used for HELCOM contracting parties. The numbers on top of each bar show the percentage share of each contribution to the total. Example: Denmark stands for 7.3% of the airborne nitrogen deposition to the Baltic Sea.

**Table 1.** Transfer coefficients for oxidized, reduced and total nitrogen from different countries. The table 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 2021.

| | DK | EE | FI | DE | LV | LT | PL | RU | SE | BAS | NOS | FR | GB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ox-N** | 11 % | 10 % | 8 % | 5 % | 9 % | 9 % | 7 % | 0.8 % | 11 % | 18 % | 5 % | 1.6 % | 2.9 % |
| **Re-N** | 19 % | 15 % | 10 % | 5 % | 10 % | 8 % | 6 % | 0.3 % | 17 % | n.a. | n.a. | 0.8 % | 1.4 % |
| **Tot-N** | 17 % | 13 % | 9 % | 5 % | 10 % | 8 % | 6 % | 0.6 % | 15 % | 18 % | 5 % | 1.1 % | 2.2 % |

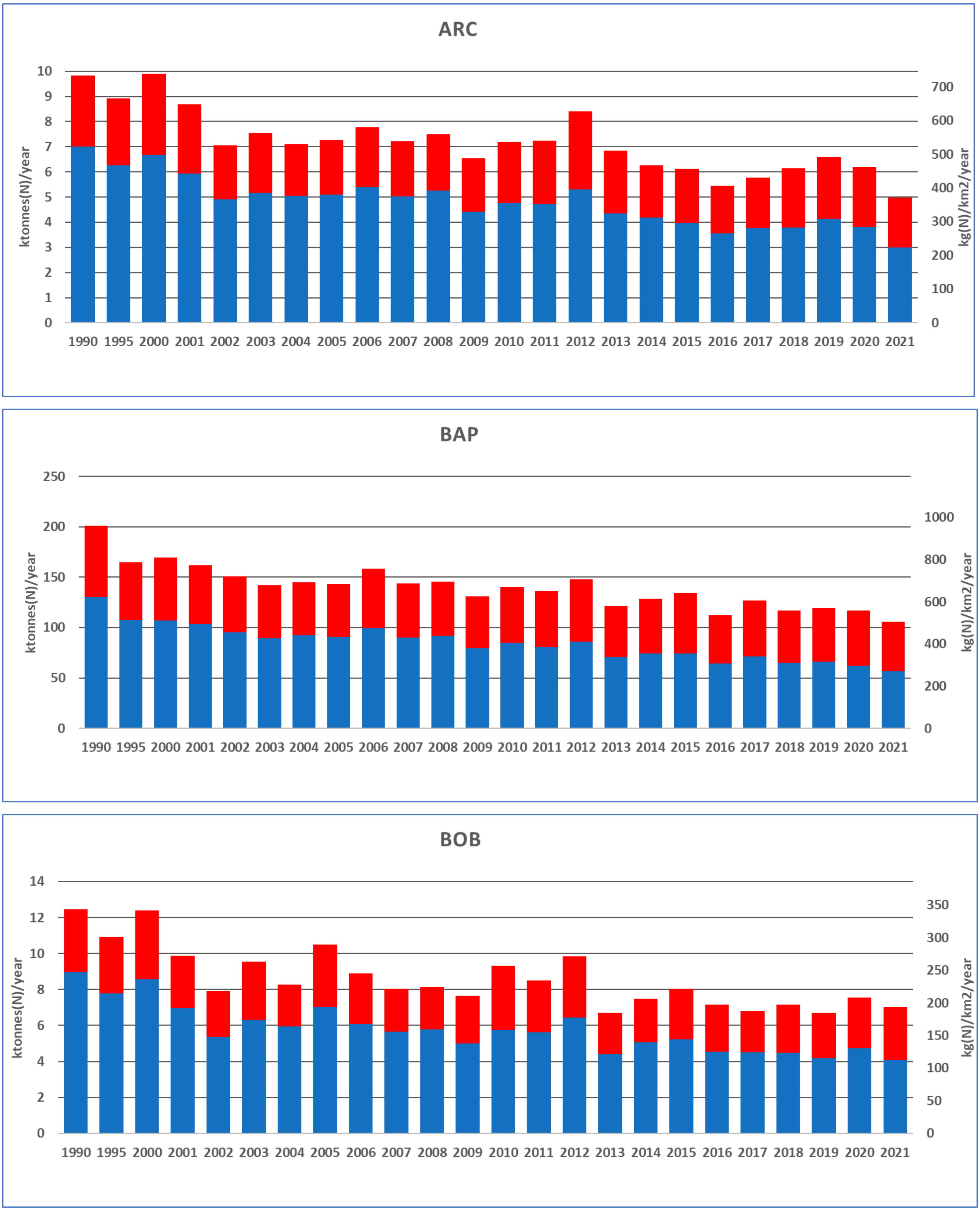
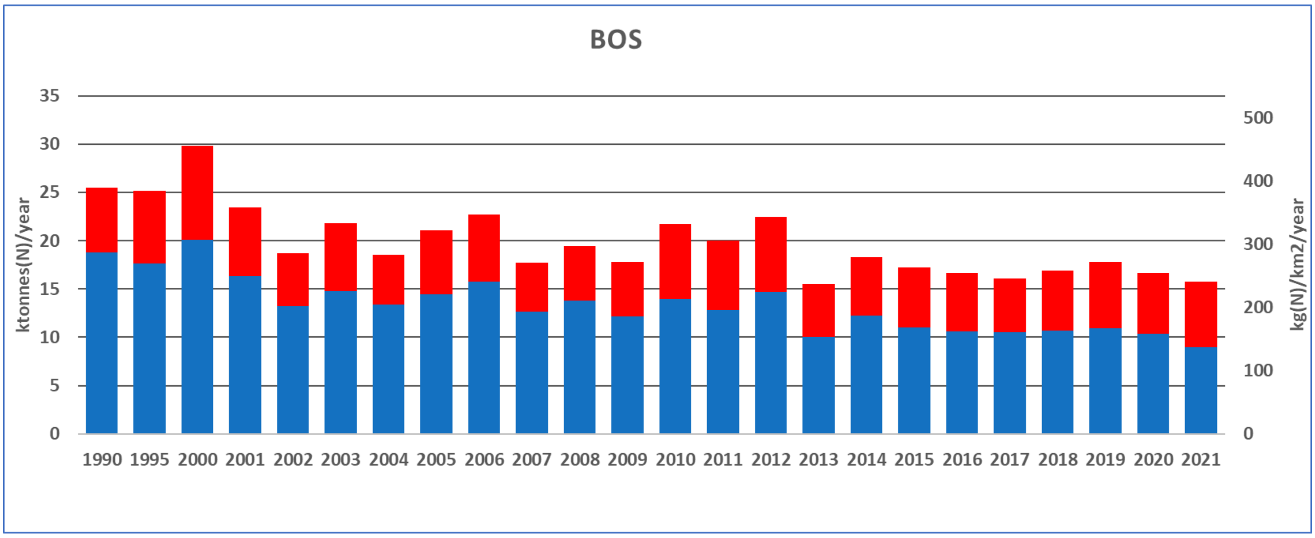
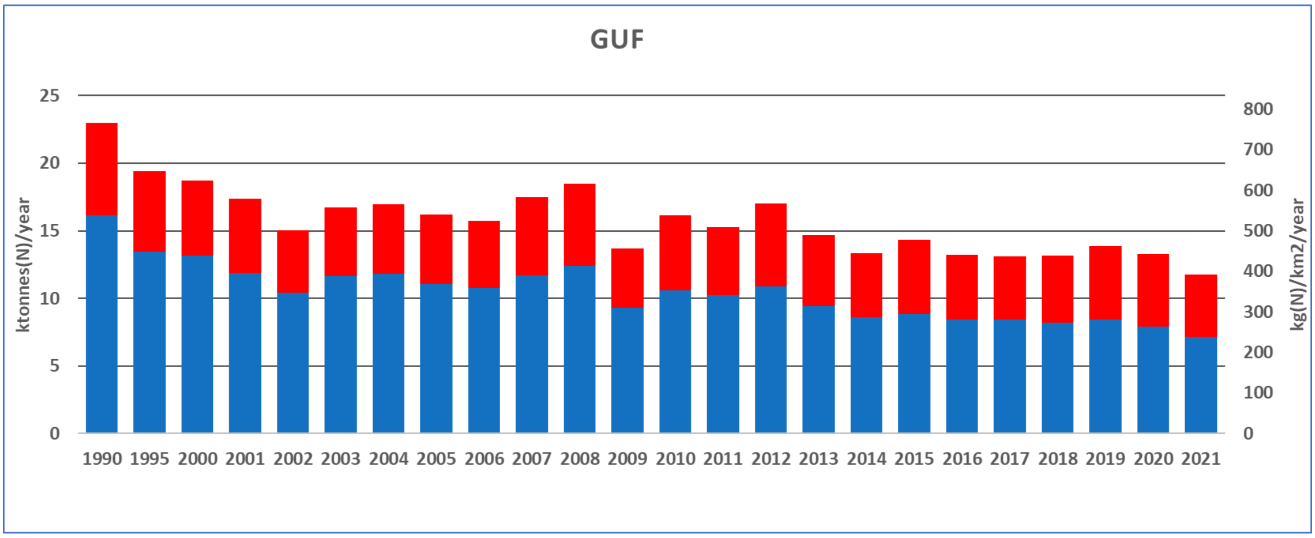



**Figure 4**. Atmospheric deposition of oxidised nitrogen (blue) and reduced nitrogen (red) to the nine sub-basins of the Baltic Sea in the period 1990 - 2021. Unit: ktonnes(N)/year. Note that the vertical scales in the plots are different. The figure continues on the next two pages. For definitions of sub-basins see Figure 5.



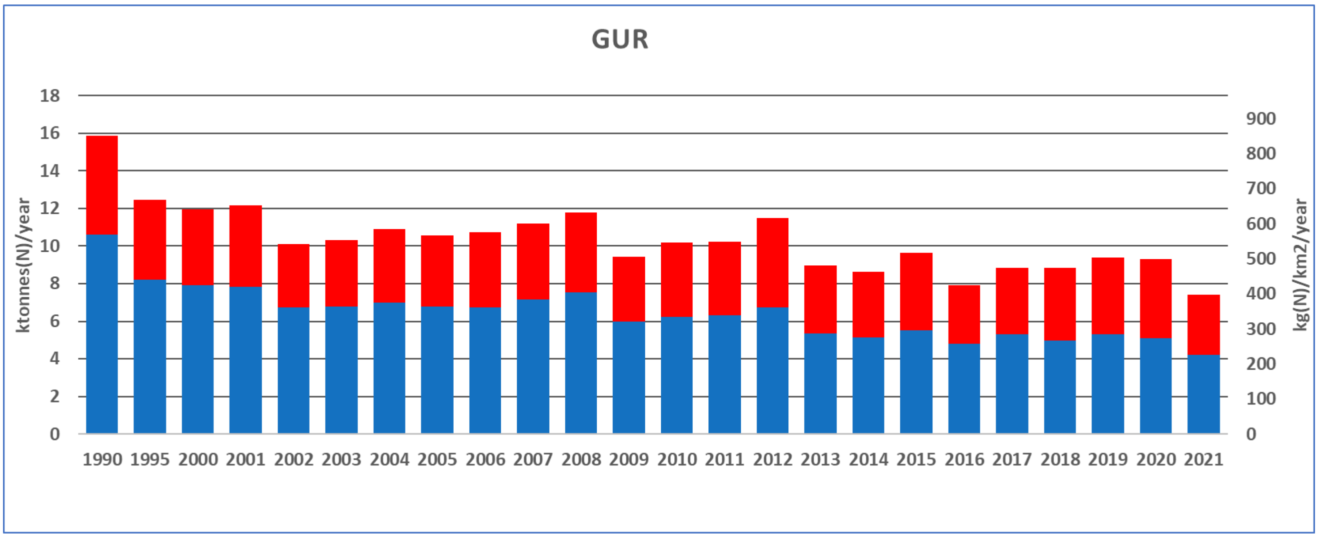
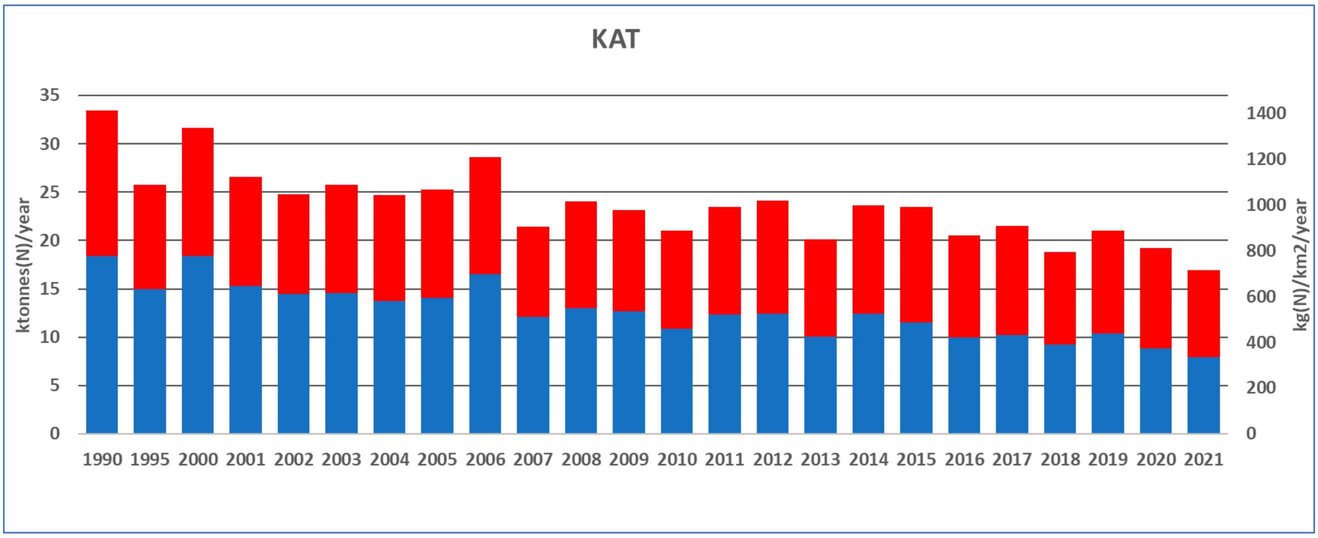
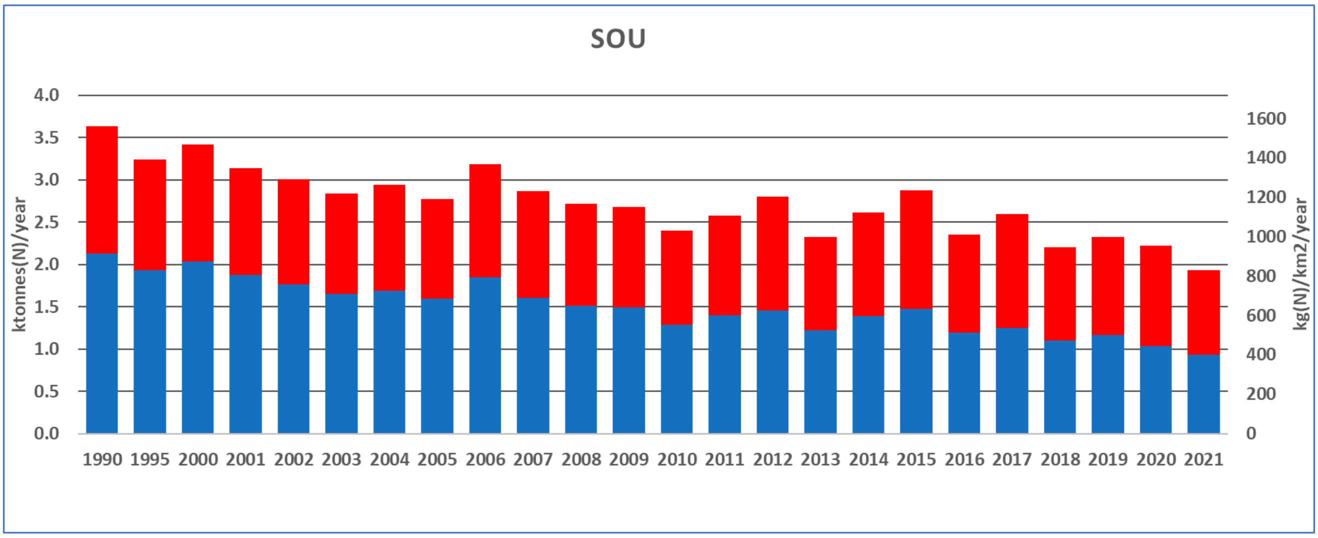




**Figure 4**. Continued.



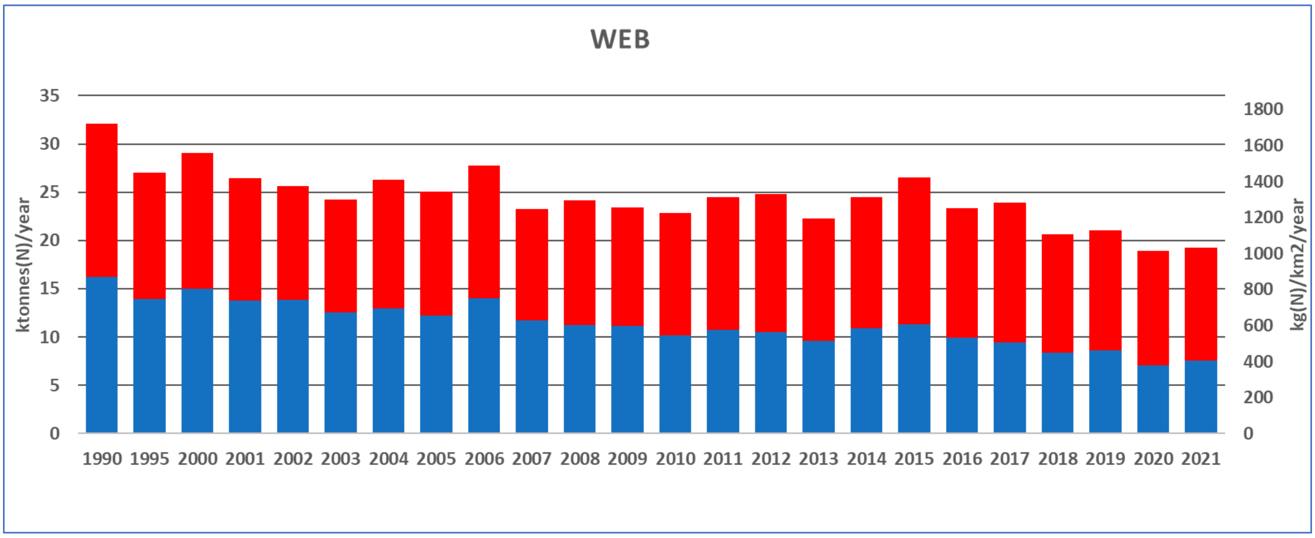
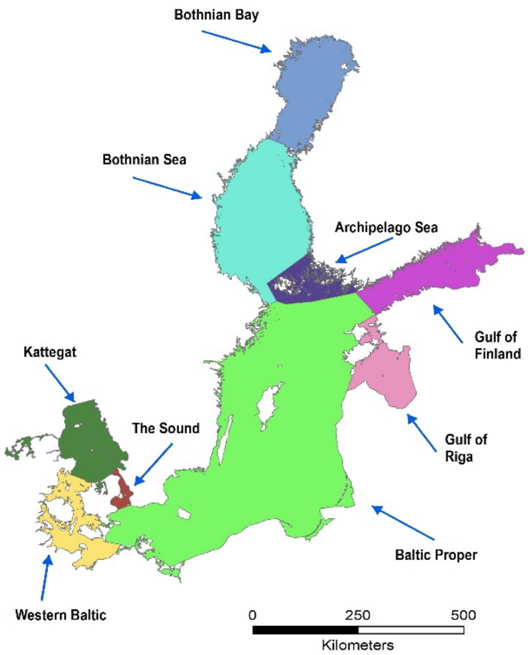




**Figure 4**. Continued.

**Table 2**. Trends in actual (non-normalized) depositions of oxidized, reduced, and total nitrogen to the nine sub-basins of the Baltic Sea. The values correspond to the slopes of the linear regression line, given in units of %/decade, calculated for the whole 32-year period (1990 – 2021), for the 1990s and for the most recent decade. Missing values mean that there is no trend that is significant at the 95% confidence level (i.e. the Mann-Kendall test yields a p-value larger than 0.05).

| Area | Oxidized Nitrogen | | | Reduced Nitrogen | | | Total Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990-2021 | 1990-2000 | 2011-2021 | 1990-2021 | 1990-2000 | 2011-2021 | 1990-2021 | 1990-2000 | 2011-2021 |
| ARC | -18.5 | - | -36.8 | -9.5 | - | - | -15.9 | - | -31.4 |
| BAP | -18.2 | -17.9 | -29.6 | -10.0 | - | - | -15.3 | -15.9 | -22.3 |
| BOB | -17.6 | - | -27.8 | - | - | - | -14.1 | - | - |
| BOS | -16.8 | - | -29.7 | - | - | - | -12.3 | - | - |
| GUF | -18.0 | -18.8 | -30.4 | -10.3 | -18.6 | - | -15.7 | -18.7 | -22.7 |
| GUR | -19.5 | -25.5 | -33.7 | -12.4 | -22.9 | - | -17.1 | -24.6 | - |
| KAT | -18.4 | - | -36.0 | -12.8 | - | - | -15.9 | - | -27.8 |
| SOU | -18.1 | -4.4 | -33.6 | -10.7 | - | - | -15.1 | -6.0 | -24.9 |
| WEB | -17.2 | - | -29.8 | - | - | -14.3 | -12.9 | - | -21.2 |




| 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 3**. Actual depositions of oxidised nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2021. The bottom row ('Ref') shows the average for the 1997 – 2003 reference period. 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 | |
| 1990 | 7.0 | 130 | 8.9 | 18.8 | 16.2 | 10.6 | 18.4 | 2.1 | 16.2 | 228 |
| 1991 | 7.0 | 123 | 8.4 | 18.2 | 15.6 | 10.4 | 17.3 | 2.1 | 15.5 | 217 |
| 1992 | 6.8 | 125 | 9.0 | 19.8 | 15.6 | 10.0 | 17.7 | 2.2 | 15.9 | 222 |
| 1993 | 6.8 | 124 | 8.0 | 19.2 | 13.3 | 8.7 | 16.9 | 2.2 | 15.7 | 215 |
| 1994 | 6.3 | 120 | 6.9 | 16.7 | 13.5 | 8.5 | 17.2 | 2.1 | 16.5 | 207 |
| 1995 | 6.3 | 108 | 7.8 | 17.7 | 13.4 | 8.2 | 15.0 | 1.9 | 14.0 | 192 |
| 1996 | 6.4 | 106 | 6.8 | 16.7 | 13.4 | 8.0 | 14.4 | 1.8 | 13.2 | 186 |
| 1997 | 5.2 | 95.2 | 5.7 | 14.6 | 11.8 | 7.5 | 14.9 | 1.8 | 13.1 | 170 |
| 1998 | 6.3 | 114 | 8.0 | 17.9 | 13.6 | 8.4 | 16.0 | 2.1 | 16.1 | 203 |
| 1999 | 6.4 | 108 | 7.5 | 18.1 | 13.0 | 8.2 | 18.1 | 1.9 | 14.1 | 195 |
| 2000 | 6.7 | 107 | 8.6 | 20.1 | 13.1 | 7.9 | 18.4 | 2.0 | 15.0 | 199 |
| 2001 | 5.9 | 103 | 7.0 | 16.3 | 11.9 | 7.8 | 15.3 | 1.9 | 13.7 | 183 |
| 2002 | 4.9 | 95.1 | 5.4 | 13.2 | 10.4 | 6.7 | 14.5 | 1.8 | 13.8 | 166 |
| 2003 | 5.2 | 89.6 | 6.3 | 14.8 | 11.6 | 6.8 | 14.6 | 1.7 | 12.5 | 163 |
| 2004 | 5.0 | 92.4 | 6.0 | 13.4 | 11.8 | 7.0 | 13.8 | 1.7 | 13.0 | 164 |
| 2005 | 5.1 | 90.8 | 7.0 | 14.5 | 11.1 | 6.8 | 14.1 | 1.6 | 12.3 | 163 |
| 2006 | 5.4 | 99.2 | 6.1 | 15.8 | 10.8 | 6.7 | 16.6 | 1.9 | 14.1 | 176 |
| 2007 | 5.0 | 90.1 | 5.7 | 12.6 | 11.7 | 7.2 | 12.1 | 1.6 | 11.7 | 158 |
| 2008 | 5.3 | 91.9 | 5.8 | 13.8 | 12.4 | 7.5 | 13.0 | 1.5 | 11.2 | 162 |
| 2009 | 4.4 | 79.7 | 5.0 | 12.1 | 9.3 | 6.0 | 12.7 | 1.5 | 11.2 | 142 |
| 2010 | 4.8 | 84.7 | 5.8 | 13.9 | 10.6 | 6.2 | 10.8 | 1.3 | 10.2 | 148 |
| 2011 | 4.7 | 80.7 | 5.6 | 12.8 | 10.2 | 6.3 | 12.3 | 1.4 | 10.8 | 145 |
| 2012 | 5.3 | 86.0 | 6.5 | 14.7 | 10.9 | 6.7 | 12.4 | 1.5 | 10.5 | 154 |
| 2013 | 4.3 | 70.9 | 4.4 | 10.0 | 9.4 | 5.3 | 10.1 | 1.2 | 9.6 | 125 |
| 2014 | 4.2 | 74.0 | 5.1 | 12.2 | 8.6 | 5.1 | 12.4 | 1.4 | 10.9 | 134 |
| 2015 | 4.0 | 74.5 | 5.2 | 11.0 | 8.9 | 5.5 | 11.6 | 1.5 | 11.3 | 133 |
| 2016 | 3.6 | 64.4 | 4.5 | 10.6 | 8.5 | 4.8 | 10.0 | 1.2 | 9.9 | 117 |
| 2017 | 3.8 | 71.3 | 4.5 | 10.5 | 8.4 | 5.3 | 10.2 | 1.3 | 9.4 | 125 |
| 2018 | 3.8 | 64.9 | 4.5 | 10.7 | 8.2 | 5.0 | 9.2 | 1.1 | 8.4 | 116 |
| 2019 | 4.1 | 66.0 | 4.2 | 10.9 | 8.4 | 5.3 | 10.4 | 1.2 | 8.6 | 119 |
| 2020 | 3.8 | 62.1 | 4.7 | 10.4 | 7.9 | 5.1 | 8.8 | 1.0 | 7.1 | 111 |
| 2021 | 3.0 | 56.8 | 4.1 | 9.0 | 7.1 | 4.2 | 7.9 | 0.9 | 7.6 | 101 |
| **Ref** | **5.8** | **102** | **6.9** | **16.4** | **12.2** | **7.6** | **16.0** | **1.9** | **14.1** | **183** |

**Table 4**. Actual depositions of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2021. The bottom row ('Ref') shows the average for the 1997 – 2003 reference period. 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 | |
| 1990 | 2.8 | 71.2 | 3.5 | 6.7 | 6.8 | 5.2 | 15.0 | 1.5 | 15.9 | 129 |
| 1991 | 2.8 | 66.1 | 3.2 | 6.7 | 7.2 | 5.7 | 13.7 | 1.5 | 14.1 | 121 |
| 1992 | 3.1 | 67.5 | 4.2 | 8.1 | 8.5 | 5.6 | 13.6 | 1.5 | 14.6 | 127 |
| 1993 | 2.9 | 67.3 | 3.0 | 8.1 | 5.9 | 4.5 | 13.0 | 1.4 | 13.5 | 120 |
| 1994 | 2.2 | 62.2 | 2.5 | 5.6 | 6.0 | 4.6 | 12.4 | 1.4 | 14.2 | 111 |
| 1995 | 2.7 | 57.2 | 3.1 | 7.5 | 6.0 | 4.2 | 10.8 | 1.3 | 13.0 | 106 |
| 1996 | 2.8 | 57.9 | 2.5 | 7.1 | 6.8 | 4.6 | 10.2 | 1.1 | 11.1 | 104 |
| 1997 | 1.9 | 50.7 | 2.1 | 4.8 | 4.4 | 3.6 | 11.3 | 1.3 | 12.5 | 93 |
| 1998 | 2.6 | 63.5 | 3.4 | 7.2 | 6.1 | 4.4 | 12.3 | 1.5 | 15.3 | 116 |
| 1999 | 2.8 | 59.7 | 3.3 | 7.5 | 5.8 | 4.3 | 13.7 | 1.3 | 13.1 | 111 |
| 2000 | 3.2 | 62.6 | 3.8 | 9.7 | 5.6 | 4.0 | 13.2 | 1.4 | 14.1 | 118 |
| 2001 | 2.8 | 58.5 | 2.9 | 7.1 | 5.5 | 4.3 | 11.3 | 1.3 | 12.7 | 106 |
| 2002 | 2.1 | 55.6 | 2.5 | 5.5 | 4.6 | 3.4 | 10.3 | 1.2 | 11.8 | 97 |
| 2003 | 2.4 | 52.5 | 3.2 | 7.0 | 5.1 | 3.5 | 11.2 | 1.2 | 11.7 | 98 |
| 2004 | 2.0 | 52.4 | 2.3 | 5.2 | 5.1 | 3.9 | 10.9 | 1.3 | 13.3 | 97 |
| 2005 | 2.2 | 52.2 | 3.5 | 6.6 | 5.1 | 3.8 | 11.2 | 1.2 | 12.8 | 98 |
| 2006 | 2.4 | 59.0 | 2.8 | 6.9 | 5.0 | 4.0 | 12.1 | 1.3 | 13.7 | 107 |
| 2007 | 2.2 | 53.9 | 2.4 | 5.1 | 5.8 | 4.0 | 9.3 | 1.3 | 11.5 | 96 |
| 2008 | 2.2 | 53.8 | 2.3 | 5.7 | 6.1 | 4.2 | 11.0 | 1.2 | 12.9 | 100 |
| 2009 | 2.1 | 51.4 | 2.6 | 5.7 | 4.4 | 3.5 | 10.5 | 1.2 | 12.2 | 94 |
| 2010 | 2.4 | 55.7 | 3.6 | 7.8 | 5.5 | 4.0 | 10.2 | 1.1 | 12.7 | 103 |
| 2011 | 2.5 | 55.6 | 2.9 | 7.2 | 5.0 | 3.9 | 11.1 | 1.2 | 13.7 | 103 |
| 2012 | 3.1 | 62.0 | 3.4 | 7.8 | 6.2 | 4.8 | 11.7 | 1.3 | 14.3 | 114 |
| 2013 | 2.5 | 50.8 | 2.3 | 5.5 | 5.3 | 3.6 | 10.0 | 1.1 | 12.6 | 94 |
| 2014 | 2.1 | 54.6 | 2.4 | 6.1 | 4.7 | 3.5 | 11.2 | 1.2 | 13.6 | 100 |
| 2015 | 2.2 | 60.0 | 2.8 | 6.2 | 5.4 | 4.1 | 11.9 | 1.4 | 15.2 | 109 |
| 2016 | 1.9 | 48.0 | 2.6 | 6.0 | 4.8 | 3.1 | 10.5 | 1.2 | 13.4 | 92 |
| 2017 | 2.0 | 55.3 | 2.3 | 5.5 | 4.7 | 3.5 | 11.3 | 1.3 | 14.5 | 100 |
| 2018 | 2.4 | 51.9 | 2.7 | 6.3 | 5.0 | 3.9 | 9.6 | 1.1 | 12.3 | 95 |
| 2019 | 2.5 | 53.2 | 2.5 | 6.9 | 5.5 | 4.1 | 10.6 | 1.2 | 12.4 | 99 |
| 2020 | 2.4 | 54.9 | 2.8 | 6.3 | 5.4 | 4.2 | 10.5 | 1.2 | 11.9 | 99 |
| 2021 | 2.0 | 49.1 | 2.9 | 6.8 | 4.7 | 3.2 | 9.1 | 1.0 | 11.7 | 91 |
| **Ref** | **2.5** | **57.6** | **3.0** | **7.0** | **5.3** | **3.9** | **11.9** | **1.3** | **13.0** | **106** |

**Table 5**. Actual depositions of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1990 – 2021. The bottom row ('Ref') shows the average for the 1997 – 2003 reference period. 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 | |
| 1990 | 9.8 | 201 | 12.5 | 25.5 | 23.0 | 15.8 | 33.4 | 3.6 | 32.1 | 357 |
| 1991 | 9.8 | 189 | 11.6 | 25.0 | 22.8 | 16.1 | 30.9 | 3.6 | 29.6 | 338 |
| 1992 | 9.9 | 192 | 13.2 | 27.9 | 24.1 | 15.6 | 31.2 | 3.7 | 30.5 | 349 |
| 1993 | 9.7 | 192 | 11.0 | 27.3 | 19.2 | 13.2 | 29.9 | 3.6 | 29.2 | 335 |
| 1994 | 8.6 | 182 | 9.4 | 22.3 | 19.5 | 13.2 | 29.6 | 3.5 | 30.7 | 318 |
| 1995 | 8.9 | 165 | 10.9 | 25.2 | 19.4 | 12.4 | 25.8 | 3.2 | 27.0 | 298 |
| 1996 | 9.2 | 163 | 9.3 | 23.8 | 20.2 | 12.6 | 24.6 | 2.9 | 24.2 | 290 |
| 1997 | 7.1 | 146 | 7.7 | 19.4 | 16.2 | 11.0 | 26.2 | 3.1 | 25.6 | 262 |
| 1998 | 9.0 | 178 | 11.4 | 25.0 | 19.7 | 12.8 | 28.3 | 3.6 | 31.3 | 319 |
| 1999 | 9.2 | 167 | 10.8 | 25.6 | 18.7 | 12.5 | 31.8 | 3.2 | 27.2 | 306 |
| 2000 | 9.9 | 169 | 12.4 | 29.8 | 18.7 | 11.9 | 31.6 | 3.4 | 29.1 | 316 |
| 2001 | 8.7 | 162 | 9.9 | 23.4 | 17.4 | 12.2 | 26.5 | 3.1 | 26.5 | 290 |
| 2002 | 7.1 | 151 | 7.9 | 18.7 | 15.0 | 10.1 | 24.8 | 3.0 | 25.6 | 263 |
| 2003 | 7.6 | 142 | 9.5 | 21.8 | 16.7 | 10.3 | 25.8 | 2.8 | 24.3 | 261 |
| 2004 | 7.1 | 145 | 8.3 | 18.6 | 17.0 | 10.9 | 24.7 | 2.9 | 26.3 | 261 |
| 2005 | 7.3 | 143 | 10.5 | 21.1 | 16.2 | 10.5 | 25.2 | 2.8 | 25.0 | 262 |
| 2006 | 7.8 | 158 | 8.9 | 22.7 | 15.8 | 10.7 | 28.6 | 3.2 | 27.7 | 284 |
| 2007 | 7.2 | 144 | 8.1 | 17.7 | 17.5 | 11.2 | 21.5 | 2.9 | 23.2 | 253 |
| 2008 | 7.5 | 146 | 8.1 | 19.5 | 18.5 | 11.8 | 24.1 | 2.7 | 24.1 | 262 |
| 2009 | 6.5 | 131 | 7.6 | 17.8 | 13.7 | 9.4 | 23.2 | 2.7 | 23.4 | 235 |
| 2010 | 7.2 | 140 | 9.3 | 21.7 | 16.1 | 10.2 | 21.0 | 2.4 | 22.9 | 251 |
| 2011 | 7.2 | 136 | 8.5 | 20.0 | 15.2 | 10.2 | 23.5 | 2.6 | 24.5 | 248 |
| 2012 | 8.4 | 148 | 9.8 | 22.5 | 17.0 | 11.5 | 24.1 | 2.8 | 24.8 | 269 |
| 2013 | 6.9 | 122 | 6.7 | 15.5 | 14.7 | 8.9 | 20.1 | 2.3 | 22.2 | 219 |
| 2014 | 6.3 | 129 | 7.5 | 18.3 | 13.4 | 8.6 | 23.6 | 2.6 | 24.5 | 233 |
| 2015 | 6.1 | 134 | 8.1 | 17.2 | 14.3 | 9.6 | 23.4 | 2.9 | 26.5 | 243 |
| 2016 | 5.4 | 112 | 7.2 | 16.7 | 13.2 | 7.9 | 20.5 | 2.4 | 23.3 | 209 |
| 2017 | 5.8 | 127 | 6.8 | 16.1 | 13.1 | 8.8 | 21.5 | 2.6 | 23.9 | 225 |
| 2018 | 6.1 | 117 | 7.2 | 16.9 | 13.2 | 8.9 | 18.8 | 2.2 | 20.7 | 211 |
| 2019 | 6.6 | 119 | 6.7 | 17.8 | 13.9 | 9.4 | 21.0 | 2.3 | 21.0 | 218 |
| 2020 | 6.2 | 117 | 7.6 | 16.7 | 13.3 | 9.3 | 19.3 | 2.2 | 19.0 | 210 |
| 2021 | 5.0 | 106 | 7.0 | 15.8 | 11.8 | 7.4 | 16.9 | 1.9 | 19.3 | 191 |
| **Ref** | **8.4** | **159** | **10.0** | **23.4** | **17.5** | **11.6** | **27.9** | **3.2** | **27.1** | **288** |

**Table 6**. Normalized depositions of oxidised, reduced and total nitrogen to the Baltic Sea basin in the period 1990 – 2021. The bottom row (‘Ref’) shows the average for the 1997 – 2003 reference period. Unit: ktonnes(N)/year. (Normalized deposition of total nitrogen may slightly 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 |
|---|---|---|---|
| 1990 | 239.7 | 145.4 | 388.0 |
| 1991 | 235.3 | 136.4 | 376.2 |
| 1992 | 227.2 | 129.8 | 360.6 |
| 1993 | 217.9 | 125.0 | 346.9 |
| 1994 | 211.3 | 121.2 | 336.2 |
| 1995 | 204.7 | 117.2 | 325.6 |
| 1996 | 204.7 | 115.4 | 323.7 |
| 1997 | 198.2 | 114.3 | 315.2 |
| 1998 | 193.1 | 113.5 | 308.8 |
| 1999 | 189.3 | 110.5 | 301.3 |
| 2000 | 185.9 | 107.7 | 294.3 |
| 2001 | 182.9 | 106.3 | 289.6 |
| 2002 | 178.7 | 104.8 | 283.5 |
| 2003 | 177.5 | 103.6 | 281.0 |
| 2004 | 174.8 | 102.2 | 277.0 |
| 2005 | 171.9 | 102.4 | 274.4 |
| 2006 | 170.2 | 101.7 | 271.9 |
| 2007 | 165.9 | 102.0 | 268.0 |
| 2008 | 155.4 | 100.6 | 256.5 |
| 2009 | 146.6 | 98.5 | 246.1 |
| 2010 | 146.6 | 98.1 | 245.7 |
| 2011 | 143.2 | 97.5 | 241.6 |
| 2012 | 139.6 | 97.0 | 237.5 |
| 2013 | 135.7 | 97.0 | 233.7 |
| 2014 | 131.5 | 97.7 | 230.3 |
| 2015 | 129.5 | 98.3 | 229.0 |
| 2016 | 126.3 | 98.0 | 225.6 |
| 2017 | 124.7 | 98.6 | 224.8 |
| 2018 | 120.5 | 97.5 | 218.9 |
| 2019 | 115.9 | 94.9 | 211.2 |
| 2020 | 105.7 | 93.8 | 199.2 |
| 2021 | 106.5 | 90.5 | 196.8 |
| **Ref** | **186.5** | **108.7** | **296.2** |

# 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 rv5.0. Emission data based on official data submissions from the HELCOM countries received by June 2023 were 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 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 1990 – 2021.

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 rv4.45. 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 interannual 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:

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