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German material flow accounts: New methodology and estimations of emissions to water

Final technical report on material flow accounts within the project of enhancing environmental-economic accounts reporting on water, wastewater and emissions to water

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Abbreviations and acronyms

EEA	European Environmental Agency
EPER	European Pollutant Emission Register
EUROSTAT	European Statistical Office
EW-MFA	Economy-Wide Material Flow Accounts
IKSR	'Internationale Kommission zum Schutz des Rheins' (IKSR) [International Commission for the Protection of the Rhine against Pollution]
IW	Irrigation water
IWS	Improving waste statistics
MFA	Material flow accounts
NACE	Statistical Classification of Economic Activities in the European Community ['nomenclature statistique des activités économiques dans la Communauté européenne']
PRTR	Pollutant Release and Transfer Register
SEEA-CF	System of Environmental-Economic Accounting – Central Framework
StBA	Statistisches Bundesamt [Federal Statistical Office Germany]
UBA	Umweltbundesamt [German Federal Environment Agency]

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1 Project objectives and activities

This final report is part of the Eurostat project 2020-DE_IWSWAMFA, consisting of the three subprojects:

- Improving waste statistics (IWS)
- Improving water accounts (WA)
- Improving material flow accounts (MFA)

This project report covers the subproject 'improving material flow accounts' (MFA). It aims to develop a suitable estimation method for emissions to water in Germany because this information is part of the German 'Economy-Wide Material Flow Accounts' (EW-MFA). Being part of environmental-economic accounts and providing a comprehensive quantitative overview of the interaction between environment and economy, the material flow accounts in particular describe material flows between the domestic environment, the domestic economy and foreign economies. This report presents the core results of project work conducted in 2023.

German material flow accounts have a long tradition and data are available starting with the reporting year 1994. They provide comprehensive information on the withdrawal of raw materials (energy sources, ores, other mineral raw materials, biomass) from the domestic environment by human activities, as well as on the import and export of raw materials and goods manufactured from these. These raw materials and goods are then used in the domestic economy, exported or returned to the environment. The latter also comprises the formation of residual materials or pollutants during processing and use of raw materials and goods. In detail, this domestic processed output covers emissions to air, emissions in wastewater as well as dissipative usage (e.g. organic or mineral fertilisers, pesticides) and dissipative losses (tyre and brake abrasion, for instance).

The conceptual framework of the material flow accounts is based on international and European standardised recommendations. The two principal guidelines are the 'System of Environmental-Economic Accounting – Central Framework' (SEEA-CF) as an international statistical standard of the United Nations, and the 'Economy-Wide Material Flow Accounts (EW-MFA) Handbook' published by the European Statistical Office (Eurostat).

Up to now, in the German material flow accounts as provided by the Federal Statistical Office (StBA) data on emissions to water exist only until 2001. These values are based on detailed estimations further described in subchapter 2.2. Production of MFA data by the StBA is necessary to fulfil national reporting obligations to Eurostat according to regulation (EU) 691/2011 on European environmental economic accounts. Even though reporting on domestic processed output is not yet obligatory under the terms of regulation (EU) 691/2011, it is a voluntary part of Eurostat's annual data collection on EW-MFA. Since the StBA does not provide any data on emissions to water, Eurostat performs and publishes its own estimations for Germany for the years 2002 and onwards. These estimations are based on the 'Waterbase – Emissions' database set up by the European Environment Agency (EEA). This database provides information on the "status and quality of Europe's rivers, lakes, groundwater bodies and transitional, coastal and marine waters, on the quantity of Europe's water resources, and on the emissions to surface waters from point and diffuse sources of pollution" (EEA, 2023).

Against this backdrop, the project work presented here aimed to establish a new annual estimation for emissions to water in Germany, to fill the currently existing gap in the German material flow accounts and in order to be able to fill in Eurostat's EW-MFA questionnaire more comprehensively.

The first step of the project comprised a review of the formal requirements concerning emissions to water, including definitions of relevant reporting items and delineation from other positions of material flow accounts, given in the SEEA-CF and the EW-MFA handbook. This information – provided in chapter 2 – is supplemented by an examination of the old estimation that was based on project activities dating from 2001.

Because the old estimation dates back to two decades and is no longer applied, it was necessary to embark on a next step to investigate possible data sources for a more up-to-date estimation. Chapter 3 presents the data sources considered, including a review of possible limitations regarding the quality and comprehensiveness of the data, as well as information on further data processing and data validation approaches. Chapter 4 sets out the results regarding emissions to water, as a result of which the final selection of the estimation was based on the criterion that at the very least the requirements laid out in the Eurostat EW-MFA questionnaire should be fulfilled. Finally, chapters 5 and 6 provide information on possible future improvements and conclude with some summarising remarks about the project as a whole.

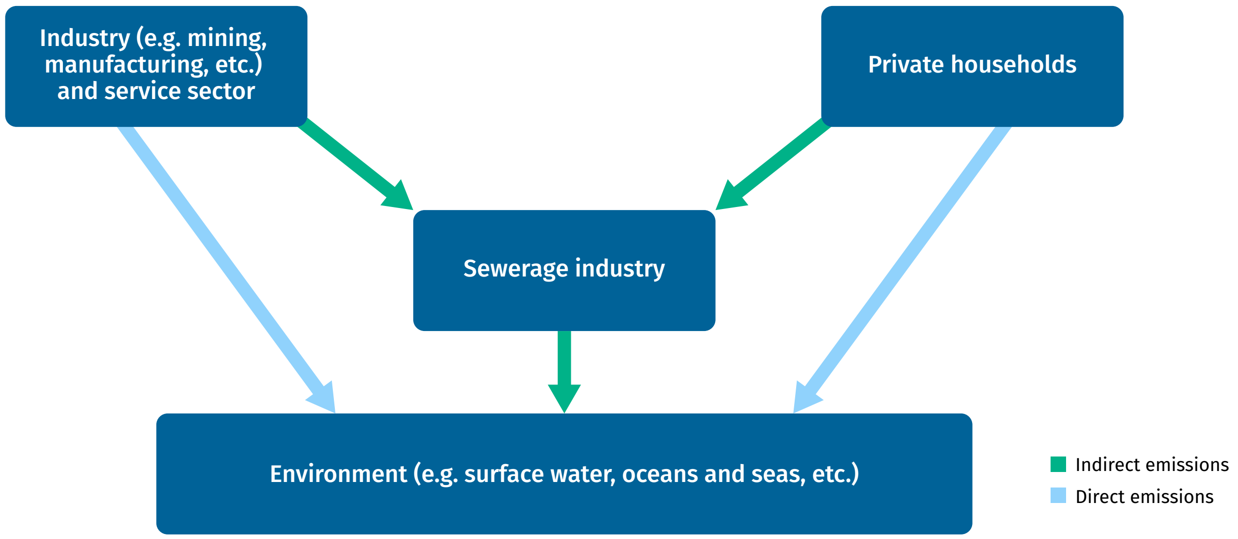
2 Conceptual background

2.1 Definitions regarding emissions to water

According to the SEEA-CF, emissions are defined as “[...] a type of residuals (...) that are released by establishments and households into the air, water or soil as a result of production, consumption and accumulation processes” (United Nations, 2012, p. 85). This definition implies that the focus is on flows from the economy to the environment. Flows of residuals within the environment are therefore irrelevant for our MFA reporting. All emissions are reported in units of mass (kilogrammes, tons, thousand tons and so on).

Regarding emissions to water resources, two types of source are distinguished: point sources and non-point sources. Non-point sources, also called diffuse sources, do not have a clearly definable point of origin from where emissions enter natural bodies of water. This applies for example to urban run-off that directly enters water bodies without passing through a sewerage facility or to the application of fertilisers and pesticides on agricultural areas. On the other hand, for point sources a geographical location of the release can be precisely determined. This includes for example wastewater releases of sewerage facilities, industry entities, the service sector or private households. Within the point sources a distinction between direct emission of substances into the water and indirect release of substances to sewerage systems is possible. The latter case subsequently undergoes treatment before a final release to water resources occurs. Figure 1 gives an overview of these possible point sources, including the distinction between direct and indirect emissions, using the sewerage industry as an interstation.

Figure 1:
Schematic overview of point sources for emissions to water showing the distinction between direct and indirect emissions, and using the sewerage industry as an intermediate station



Source: adapted from SEEA-CF (2012, p. 86).

Regarding the German material flow accounts as well as the Eurostat EW-MFA questionnaire, the EW-MFA handbook gives more detailed information on the types of emissions to water that need to be considered. In the questionnaire, emissions to water make up part of the ‘domestic processed output’. Table 1 displays all items covered within this topic, indicating that the emissions to water comprise a further subdivision into the following five pollutant groups:

- Nitrogen
- Phosphorus
- Heavy metals
- Other substances and (organic) materials
- Dumping of materials at sea

Here it should be emphasised that the EW-MFA handbook explicitly mentions that the emissions to water solely comprise *point* sources, whereas emissions from diffuse sources are recorded under 'MF.7.4 Dissipative use of products'.

Table 1:
Components of the Eurostat EW-MFA questionnaire table displaying 'domestic processed output'
Reporting items relevant for this project are highlighted in blue

MF.7.1 Emissions to air
MF.7.1.1 Carbon dioxide (CO_2)
...
MF.7.1.9 Non-methane volatile organic compounds (NMVOC)
MF.7.2 Waste disposal to the environment
MF.7.2 MEMO Waste disposal to controlled landfills (memo item)
MF.7.3 Emissions to water
MF.7.3.1 Nitrogen (N)
MF.7.3.2 Phosphorus (P)
MF.7.3.3 Heavy metals
MF.7.3.4 Other substances and (organic) materials
MF.7.3.5 Dumping of materials at sea
MF.7.4 Dissipative use of products
MF.7.4.1 Organic fertiliser (manure)
...
MF.7.4.8 Solvents, laughing gas and other
MF.7.5 Dissipative losses

Also, the fact stated in the SEEA-CF that flows within the environment are not to be considered is supported by the comment that emissions should be "[...] accounted for at the state they are in upon discharge to the environment" (Eurostat, 2018, p. 81).

The EW-MFA handbook also provides more detailed information on the above-mentioned five pollutant groups. Nitrogen and phosphorus comprise the sum of all compounds referring to these two elements (e.g. ammonium (NH_4), nitrate (NO_3), phosphate (PO_4), etc.). These feature in wastewater flows from private households and from industrial sources. However, agriculture is excluded since this sector's emissions of nitrogen and phosphorus – in the form of fertiliser and pesticide application – are included in the 'Dissipative use of products' category. Emissions of heavy metals occur via municipal and industrial discharges only. The position 'Other substances and (organic) materials' can be regarded as a collective position for all other pollutants. When it comes to this group in particular, the detection of organic material is challenging, because reporting of this relies on the measurement of *indirect* indicators. According to the EW-MFA handbook, the most common indices are:

- Biological oxygen demand (BOD)
- Chemical oxygen demand (COD)
- Total organic carbon (TOC)
- Absorbable organic halogen compounds (AOX)

An example of AOX pollutants are LHKW (*leichtflüchtige halogenierte Kohlenwasserstoffe* or volatile halogenated hydrocarbons), like tetrachloroethylene and trichloroethylene. Both are widely used in the industrial sector as solvents or extraction agents and are released into natural water bodies during transport, decanting or as a result of accidental emission. They pose risks to the environment and to people and animals because they are not biodegradable in water and have toxic and carcinogenic properties (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz, n. d.).

Finally, the category 'Dumping of materials at sea' refers to the release of pollutants and other materials into the sea by the shipping industry. Dredging as part of the unused domestic extraction is excluded, because these weights are already recorded on the material input side – the project does not further investigate this reporting item as emissions due to dredging comprise an extremely small share of emissions to water in Germany.

For the sake of completeness, it should be noted that the SEEA-CF contains what are known as 'supply tables' and 'use tables' in the context of emissions to water. These provide more detailed information, for example regarding the origin or final destination of a range of pollutants. As these are not relevant for the material flow accounts, they are not further considered in this project report. In particular, the project does not aim to develop a comprehensive account with information on supply and use for emissions to water.

2.2 Old estimations

2.2.1 Description

In the course of two research projects, an estimation for emissions to water was conducted for 1991 to 1998 (Jenseit et al., 2001) and 1999 to 2001 (Jenseit et al., 2004). These projects considered the following pollutants:

- Chemical oxygen demand (COD)
- Biochemical oxygen demand (BOD)
- Adsorbable organic halides (AOX)
- Phosphorous or compounds thereof (P-total)
- Ammonium nitrogen (NH4-N)
- Total nitrogen (ammonium, nitrite, nitrate, organic N-compounds) (N-total)

Regarding the required reporting items in the German material flow accounts and the Eurostat EW-MFA questionnaire, total phosphorus, total nitrogen and 'Other substances' (with COD, BOD and AOX) can be reported; however, the heavy metals are missing.

Both projects only accounted for non-diffuse anthropogenic emission sources. Their calculations were characterised by the fact that the single emission sources were estimated separately for different economic groups, based on the 'Statistical Classification of Economic Activities in the European Community' (NACE), NACE Rev 1.1:

- NACE A, B – Agriculture and fishery
- NACE C, D – Mining and quarrying and industry
- NACE E – Energy supply
- NACE E – Water supply
- NACE 90 – Sewerage
- NACE F-P – Service sector without private households
- Private households

The main data source for the estimations were the publications of the German water statistics authorities covering 'non-public water supply and wastewater disposal' and 'public water supply and wastewater disposal'. These provide quantitative information on different pollutants in the wastewater for certain industry sectors and for pollutants occurring in the wastewater management of public entities (see table 2). Regarding the industry sectors, only pollutants directly emitted to natural water bodies were taken into account. Pollutants in wastewater transmitted to the sewerage system were distributed to the public wastewater management (NACE 90). Additional estimations were necessary, because NACE A, B, NACE F-P and private households were not covered by the corresponding surveys.

Regarding NACE A, B (Agriculture and fishery), only farmyard run-offs were considered, representing losses occurring during storage or decanting of fertilisers, pesticides or other materials. It was assumed that these run-offs reach natural water bodies relatively quickly, due to the presence of solid or sealed surfaces on many farms. For the different pollutants, coefficients were based on the total volumes and weights of the material considered. The general formula can be described as follows:

Emission quantity = material quantity used * coefficient for emission * coefficient for pollutant content

For the service sector (NACE F-P) as well as for private households, emissions were estimated based on wastewater volumes multiplied with coefficients for the different pollutants. Wastewater volumes comprised both direct submission to natural water bodies as well as delivery to the sewerage system. The coefficients were derived from the data on pollutant content recorded in the survey on ‘public water supply and wastewater disposal’.

A key task for nearly all economic sectors has been to differentiate between direct and indirect emissions. Data on direct emission of the different pollutants can be readily obtained from the survey on ‘non-public water supply and wastewater disposal’ (apart for the exemptions mentioned above). The indirect emissions are those submitted to the public sewerage system and these emissions are therefore also reported in the survey on ‘public water supply and wastewater disposal’.

Since German water statistics data – and therefore also the information on wastewater volumes and pollutant contents – is only available at a three-year interval, an *annual* estimation for the interim years was also implemented. This was conducted by linear interpolations of coefficients and wastewater volumes.

2.2.2 Limitations

One major disadvantage of the old estimation is the incomplete data provision by the German water statistics. Table 2 provides an overview of the data availability, structured by economic sectors and type of emission. Besides the previously mentioned lack of data for some economic sectors, another drawback is that not every type of emission is available for each sector. This can be attributed to the fact that not every pollutant is equally relevant for each economic sector; nevertheless this is still a source of inaccuracy in the data.

Table 2:
Overview of data availability from water statistics regarding emissions to water until 2001

NACE Rev. 1.1	Economic sector	Type of emission					
		AOX	CSB	BSB 5[1]	Phosphorus	Ammonium nitrogen	Total nitrogen
A, B	Agriculture and fishery	✕	✕	✕	✕	✕	✕
C, D	Industry	✓	✓	✓	✕	✕	✕
E	Energy supply[2]	✓	✓	✕	✕	✕	✕
E	Water supply	–	–	–	–	–	–
90	Sewerage	✓	✓	✓	✓	✓	✓
F-P	Service sector	✕	✕	✕	✕	✕	✕
P	Private households	✕	✕	✕	✕	✕	✕

✓ = data available
✕ = no information
– = not relevant for emissions to water
1) BSB5 for NACE C, D – Industry only available until 1995
2) AOX and CSB only available as of 1998

Another limitation is the three-yearly data availability of the water statistics data, which is ‘solved’ by a linear interpolation of coefficients and wastewater volumes. Of course, this method is not able to account for specific features of the single interim years or for possible accidents leading to outstanding pollutant contents in emissions to water.

3 New estimation for emissions to water

3.1 Data sources

Because the old estimation of emissions to water within the framework of the German material flow accounts dates back to 2004, this project has conducted a detailed examination of possible new data sources. The focus was on the basic requirement that the data should represent as completely as possible the total annual (non-diffuse) emissions to natural water bodies in Germany by the economy as a whole. Unlike the old estimation, the current German material flow accounts as well as the Eurostat EW-MFA questionnaire do not require a differentiation by economic sectors.

3.1.1 Water statistics

Water statistics data collection is still separated into one survey on public and another on non-public water supply and wastewater disposal. Both surveys are conducted in a three-year rhythm. The most recent publication provides data on the year 2019.

Regarding the non-public survey on wastewater disposal, the new publications furthermore do not provide comprehensive information on the full range of pollutants found in wastewater. The only data given are on pollutant loads of ‘Adsorbable organic halides’ (AOX) and ‘Chemical oxygen demand’ (COD), both belonging to the pollutant category ‘Other substances’.

In contrast, the survey on public wastewater disposal provides quite detailed information about the types and amounts of pollutants contained in wastewater that is released into natural water bodies by public wastewater management authorities. In this survey, all sewerage facilities connected to 50 or more population equivalents are recorded. According to the EEA, one population equivalent is defined as ‘[...] the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day.’ (EEA, n.d.) More in general, it compares the pollutant potential of an industry (in terms of biodegradable organic matter) with a certain number of people, which would produce the same pollutant load. The following pollutants are reported within the survey on public wastewater disposal:

- Chemical oxygen demand (COD)
- Adsorbable organic halides (AOX)
- Total phosphorus (P-total)
- Total nitrogen (N-total)
- Heavy metals (mercury, cadmium, chrome, nickel, lead, copper)

It should be noted that data on heavy metals have only been available since 2013. Beside annual load (in t or kg) and average concentration (in mg/m^3 or $\mu g/m^3$), information on annual wastewater volumes and percentage of sewage plants with or without measurement of the respective pollutants is also provided. The annual wastewater volumes are composed of submitted wastewater from industries and private households as well as urban run-off, precipitation water and external water. It therefore represents the total water volumes that reach the public sewerage system.

3.1.2 Thru.de

As German water statistics do not provide information on emissions from non-public companies, we needed to consult a second main data source: for this project we made use of www.thru.de which is the official portal on direct emissions to air and water, as well as diffuse emission sources and the amounts of industrial waste for Germany. It is managed by the Umweltbundesamt (UBA) [German Federal Environment Agency] and is based on the ‘Pollutant Release and Transfer Register’ (PRTR). Its legal basis is the PRTR protocol from the conference in Rio de Janeiro in June 1992 that obliges participating members to build up a publicly available register of pollutants. The first version of this register was the ‘European Pollutant Emission Register’ (EPER) that provided data for the years 2001 and 2004. This obligation was transferred into a national law, the ‘Gesetz zur Ausführung des Protokolls über Schadstofffreisetzungs- und -verbringungsregister’ (SchadRegProtAG) [Act of Implementation of the Protocol on the Pollutant Release and

Transfer Register] in 2003, which led to the establishing of a subsequent register in Germany, the 'Pollutant Release and Transfer Register' (PRTR) (in German: Schadstofffreisetzungs- und Verbringungsregister). In 2006 the European Union issued a decree for the establishing of a European pollutant register (E-PRTR regulation).

The following two sections briefly explain the data content of, and the differences between, EPER and PRTR.

3.1.2.1 EPER

The first reporting on EPER was published in June 2004 and contained emissions data for the year 2001. Three years later in July 2007 the second report (with data for 2004) was published. This was in fact the final report, because EPER was replaced by the PRTR as of 2007.

Neither EPER nor PRTR comprise a full data collection. Only certain economic sectors are obliged to report their emissions. Additionally, these sectors only have to report in cases where their emission of a given pollutant exceeds a specified threshold value. These sectors and thresholds are defined in regulation (EC) 166/2006. The main objective is to cover at least 90 % of the total national emissions while relieving companies with presumably low emission quantities of the duty to report.

Thru.de includes two reports on the results of the EPER data for 2001 and 2004, providing aggregated information on emissions based on the following variables:

- Federal states
- Economic activity
- Type of emission
  - Air
  - Water direct
  - Water indirect
- Determination method (measurement or estimation)

The raw data for both years are not directly available on Thru.de but can be received in the form of csv-files upon request.

Regarding the data provision for the German material flow accounts and the Eurostat EW-MFA questionnaire, besides the type of emission the type of pollutant is also important. The following pollutants and the respective pollutant groups to which they belong are available, all displayed in kg/year:

- Total phosphorus (P-total)
- Total nitrogen (N-total)
- Heavy metals (mercury, cadmium, chrome, nickel, lead, copper, arsenic, zinc)
- Other substances

When comparing the pollutant groups to the reporting items in the Eurostat EW-MFA questionnaire (see table 1), it is clear that these match quite well. 'Other substances' represents a combined position for all pollutants that do not match one of the other groups. It should also be noted that the heavy metals comprise two additional compounds (arsenic and zinc) compared to those featured in the respective category in the public water statistics survey.

3.1.2.2 PRTR

In principle, the PRTR is structured in a similar way to the EPER and contains broadly the same information. Nonetheless, the PRTR reveals some notable improvements regarding:

- Number of reportable economic sectors
- Amount of reported pollutants
- Frequency and timeliness of reporting

Regarding the reporting frequency, the PRTR provides annual data as of 2007 that can be directly downloaded from Thru.de in different file formats. New data are released no later than 15 months after the end of the reporting year.

In addition, the PRTR data regarding emissions to water is separated into two distinct reports. One report covers the direct release of pollutants into water, while the other covers indirect release, i.e. the transfer of polluted wastewater to treatment facilities outside a particular industry or company. Although the EPER also differentiates between these two types of emission, these are displayed together within the same report.

With regard to the water statistics it is noteworthy that the PRTR also provides partial information on public wastewater management, but only for sewerage facilities with more than 100,000 population equivalents.

3.1.2.3 Comparison between EPER and PRTR

In general, the PRTR data are more comprehensive than the EPER data. Comparing the last reporting year of the EPER (2004) and the first one of the PRTR (2007), there is an approximately 80 % increase in the amount of different reported pollutants and an increase of 20 % in the number of different economic sectors – according to the NACE classification – with reporting obligations. The pollutants additionally covered by the PRTR in comparison to the EPER are all part of the category ‘Other substances’.

Another difference lies in the reference value of the defined threshold values. Even though the EPER distinguishes between direct and indirect emissions to natural water bodies, a company is obliged to report its emissions when the *sum* of direct and indirect emissions exceeds the threshold value. In contrast, both direct and indirect emissions in the PRTR each have *their own* threshold values that naturally differ from the joint threshold in the EPER.

Table 3 gives an overview of the number of reporting companies and reported pollutants for EPER and PRTR as well as the water statistics – representing the public wastewater management – over time. For the EPER data, direct and indirect emission (release of pollutants with the wastewater) are reported jointly, whereas for the PRTR data a distinction is drawn. To obtain the total number of companies or pollutants, direct and indirect values have to be summed. Public water statistics data only refer to indirect emissions, namely the release of wastewater by public sewerage facilities.

Table 3:
Comparison of the data quality parameters in terms of the number of companies and number of pollutants cited in the different data sources

	2001	2004	2007	2010	2013	2016	2019
Number of companies							
EPER	424	482	-	-	-	-	-
PRTR – direct	-	-	397	403	392	387	373
PRTR – indirect	-	-	412	429	425	435	438
water statistics	10,188	9,994	9,933	9,632	9,307	9,105	8,891
Number of pollutants							
EPER	24	23	-	-	-	-	-
PRTR – direct	-	-	46	40	39	38	36
PRTR – indirect	-	-	38	38	37	32	33
water statistics	4	4	4	4	10	10	10

3.1.2.4 Limitations of the EPER and PRTR data

On Thru.de two publications dealing with the quality of the PRTR data are available. The first is a thesis on quality assurance methods implemented in the data generating process (Hilliges, 2012), and the second is a report on the benefit and impact of the PRTR, conducted on behalf of the UBA (Zettl et al., 2021). Both reports state that the pollutant thresholds are set too high, which results in a failure to reach the target of 90 % emission coverage for the majority of the pollutants. More specifically, Zettl and colleagues determined that only 19 % of the examined pollutants emitted into the air attained a degree of coverage in the PRTR data of 80 % or higher. Information on emissions to water is not available but it can be assumed that coverage of this is also insufficient for the relevant years.

In addition, some presumably relevant economic sectors are missing, for example the oil and gas industry. Following on from this, it should also be noted that nuclear power plants and therefore radioactive substances do not constitute a share of the recorded pollutants. However, transmission of radioactive pollutants to air and water is subject to strictly monitored maximum values, to limit the exposure risk for animals and people (BfS, 2023).

3.2 Calculations

In general, the data sources presented in the previous chapters provide information going back to 2001. Since both sources rely on official reporting (from UBA and StBA) it seems reasonable to use these data to estimate non-diffuse emissions to natural water bodies. Nonetheless, StBA and UBA collect their data independently and based on different conditions. As a consequence, both public water statistics and the EPER/PRTR data contain information on public sewerage facilities. As already mentioned in section 3.1.1, water statistics data includes all public sewerage facilities with 50 or more population equivalents, whereas the EPER/PRTR reporting on public sewerage facilities is limited to those with more than 100,000 population equivalents. This overlap needs to be accounted for in the final calculation of the annual pollutant load.

The following sections provide more detailed information on the data processing of the two data sources. Additionally, we validated our approach by calculating an upper limit for pollutant loads. The aggregation of the different calculation elements and the final results for emissions to water are presented separately in chapter 4.

3.2.1 Water statistics

Emission data for the recorded pollutants in the public wastewater survey are available both as an annual load and as an average concentration. Since the German material flow accounts and the Eurostat EW-MFA questionnaire require the emissions data in thousand-ton units, it is possible to simply take the annual load and make some minor conversions, because in the water statistics survey the values are displayed in kg or tons depending on the pollutant.

Finally, the pollutants AOX and COD were combined under the category ‘Other substances’. In contrast, total nitrogen, total phosphorus and heavy metals are reported separately and thus already comply with the classification given in the EW-MFA questionnaire.

3.2.1.1 Annual estimation for interim years

The survey on public wastewater is published in a three-year rhythm only, beginning with the year 2001 and with the most recent publication dating from 2019. Because the German material flow accounts and the Eurostat EW-MFA questionnaire require annual data, an additional calculation for estimating the interim years is required. We decided to base this estimation on an interpolation of the pollutants’ average concentration and the total wastewater volumes. The latter can be obtained from the German water accounts, where annual data for public wastewater is available.

However, the information covering average concentration in public wastewater statistics does not refer to the *total* wastewater volume. Instead, it is an average for those wastewater volumes only where first, the treatment facility is able to measure the corresponding pollutant and second, where this measurement is above a certain detection limit. We therefore calculated a new concentration, based on the total wastewater volume, because this is necessary for calculating the interim years. This new calculation was possible on the basis of the value of the annual load, i.e. the absolute amount of a particular pollutant identified in the water statistics survey:

New concentration = annual load from water statistics / total wastewater volume from water statistics

Since the units of annual load and concentrations differ among the various pollutants, the calculations were adapted to obtain the new concentration in mg per litre.

In a next step, these new concentrations were linearly interpolated for the interim years. This was done using 'Statistical Analysis Software' (SAS) with the procedure 'PROC EXPAND'.

The final annual load for each pollutant and interim year can be calculated as follows:

Annual load for MFA reporting = new concentration * total wastewater volumes from water accounts

Note that this approach is only applied to the pollutants 'total nitrogen' and 'total phosphorus'. A detailed explanation for calculating the other pollutants is provided in chapter 4.

3.2.1.2 Annual estimation for the current end of the time series

The approach presented in the previous section was solely comprised of a retroactive estimation of the missing water statistics years. An additional requirement is an estimation at the current end of the time series, in this case for 2020 and 2021. It should be noted that this estimation is only preliminary and will be replaced by the retroactive estimation – as described in section 3.2.1.1 – as soon as water statistics data for the new reporting year (in this case 2022) become available.

The basis of the estimations on the current end is a regression performed on the available data relating to the different pollutants. In detail, we assume a linear trend for the annual loads and project this trend onto the missing years. The calculation of the regression equation was carried out in Excel.

As with the annual estimation, this approach is also only applied to 'total nitrogen' and 'total phosphorus' (see chapter 4 for further details).

Concerning heavy metals, data are available only from 2013 onwards. Thus, in addition to the annual estimation at the current end of the time series, for heavy metals an annual estimation at the beginning of the time series is required. Detailed information on this can also be found in chapter 4.

3.2.2 EPER and PRTR

EPER and PRTR data are provided as annual loads for a relatively large number of pollutants (see table 3). Similar to the water statistics data, total nitrogen and total phosphorus are already displayed at the level of detail required for the EW-MFA questionnaire and do not need further processing. To obtain the category of heavy metals, the following pollutants are aggregated:

- Mercury
- Cadmium
- Chrome
- Nickel
- Lead
- Copper
- Arsenic
- Zinc

The remaining pollutants are then summed together in the category 'Other substances'.

Because of the overlap regarding data on public wastewater treatment facilities with the water statistics, the annual loads were additionally calculated only for NACE 37.00 'Sewerage' – or, rather, for all economic sectors except NACE 37.00.

3.2.2.1 Extrapolation and annual estimation

EPER data is only available for the years 2001 and 2004, whereas the PRTR time series starts in 2007. Therefore, data for 2002, 2003, 2005 and 2006 are missing. Furthermore, as mentioned in section 3.1.2.3, EPER data is less comprehensive than PRTR because it covers fewer companies and types of pollutant.

To address this latter problem, we decided to implement an extrapolation for the reported years 2001 and 2004, based on the average number of companies and pollutants recorded in the PRTR data. In detail, we calculated the following coefficients for each of the two EPER years (t = 2001; t = 2004), based on the values set out in table 2:

Coefficient 1 for year t = number of companies in EPER year t / average number of companies in PRTR

Coefficient 2 for year t = number of pollutants in EPER year t / average number of pollutants in PRTR

In a next step, these coefficients were multiplied with the annual pollutant load given in the EPER data. This approach entails the assumption that the missing companies in the EPER have the same pollutant load as the already surveyed companies. Note that coefficient 2 is only applied to the pollutant group 'Other substances', because 'total nitrogen', 'total phosphorus' and all members of the heavy metals category are already included in the EPER data collection. Because of this, their pollutant loads are extrapolated with the help of coefficient 1.

The extrapolation of the annual pollutants' loads is then followed by their annual estimation for the years until 2007. Since we did not find any further information on non-public pollutant loads in wastewater for these years, we implemented a simple linear interpolation. As with the annual estimation of water statistics data, this interpolation was also conducted in SAS by means of the procedure 'PROC EXPAND'.

3.2.3 Maximum calculation

As an evaluation approach, we performed a so-called 'maximum' calculation. This is based on the assumption that companies respect their legal obligations regarding maximum concentrations of pollutants in their wastewater but also that they exploit these limits to the full. We separated the maximum approach into two calculations, one for the non-public companies and one for the public sewerage facilities.

Regarding the non-public companies, wastewater volumes – as reported in German water accounts – were multiplied with pollutant-specific concentrations. The latter were obtained from the 'Abwasserverordnung (AbwV)' [German wastewater directive], providing information on the maximum permitted pollutant concentrations for wastewater from private households and municipal wastewaters as well as from 56 economic sectors. Because allocating the pollutant concentrations and wastewater volumes into the various economic sectors would be a time-consuming and not always unambiguous task, we calculated an arithmetic average and the median across all economic sectors. Table 4 below gives an overview of these concentrations.

Table 4:
Maximum permitted pollutant concentrations, differentiated into private households and municipal wastewaters as well as into other economic sectors
Values are displayed in mg/l

Pollutant	Private households and municipal wastewater	Economic sectors	
		Arithmetic average	Median
COD	110.0	138.0	125.0
AOX	0.5	2.0	0.5
Total nitrogen	20.0	25.0	20.0
Total phosphorus	2.0	2.0	2.0
Heavy metals	3.0	3.0	3.0

In German water accounts, three different wastewater flows can be distinguished:

- Supply of wastewater to the public sewerage system
- Direct release of wastewater to the environment
  - Release of treated wastewater to the environment
  - Release of non-treated wastewater to the environment

Since the emissions of wastewater supplied to the public sewerage systems are ultimately recorded in the figures for the public wastewater facilities, only direct releases of wastewater (treated and non-treated) were taken into account for calculating the emissions of non-public companies.

Calculations for the public sewerage facilities are based on the same principle as the annual estimations explained in section 3.2.1.1. The total wastewater volumes of the public wastewater management from the German water accounts are multiplied with the pollutant concentrations listed in table 4.

The results of the maximum approach calculation as well as the contrast with the new calculation results are provided in section 4.4.2.

3.2.4 Emissions of minor importance

In general, we decided to base our calculations on conservative estimates. Our aim was to record the majority of the emissions in cases where a valid database is available. Comparing the above-mentioned data sources and calculations with the old calculation, some emission sources remain unconsidered:

- Direct emissions from private households
- Agricultural farmyard run-off

Direct emissions by private households relates to inhabitants who are not connected to the public sewerage system. Their wastewater volumes are for example treated in privately owned septic tanks or sometimes directly released into the environment. According to German water statistics, the share of these non-connected residents is about 3 % of the total population and with a declining tendency. Estimating their emissions is difficult, because the pollutant loads recorded in water statistics are only jointly available for private households and the industry. It would therefore not be an accurate approach to simply transfer the pollutant concentrations reported in water statistics to the wastewater volumes of non-connected residents. Given the small share of the non-connected residents and the declining tendency, we decided to refrain from estimating direct emissions by private households.

As already briefly explained in subchapter 2.2, the direct emissions of the agricultural sector consist of farmyard run-off, caused by storage or decanting of fertilisers, pesticides or other materials on agricultural premises. Losses occurring on agricultural fields come under the category of diffuse emissions, because they do not reach natural water bodies instantly. The old estimation uses coefficients from, among other sources, the 'Internationale Kommission zum Schutz des Rheins' (IKSR) [International Commission for the Protection of the Rhine against Pollution] (IKSR, 1996) that are applied to the amount of material used. Although this approach seems quite detailed and valid, the coefficients are now outdated and we were unable to identify any similar sources of new data. We refrained from applying the old coefficients on the current data because a great deal of innovation and change regarding the composition and application of fertilisers and pesticides has occurred in recent years. Furthermore, the farmyard run-off pollutant loads, calculated in the old estimation, represented only a minor emission source compared to other economic sectors. This was an additional reason for neglecting this category in our new estimations. Nevertheless, and as with the private households, we continue to keep in mind farmyard run-off and, if new coefficients become available or there are indications that these emission sources increase in relevance, we will consider implementing new calculations as a consequence.

4 Results

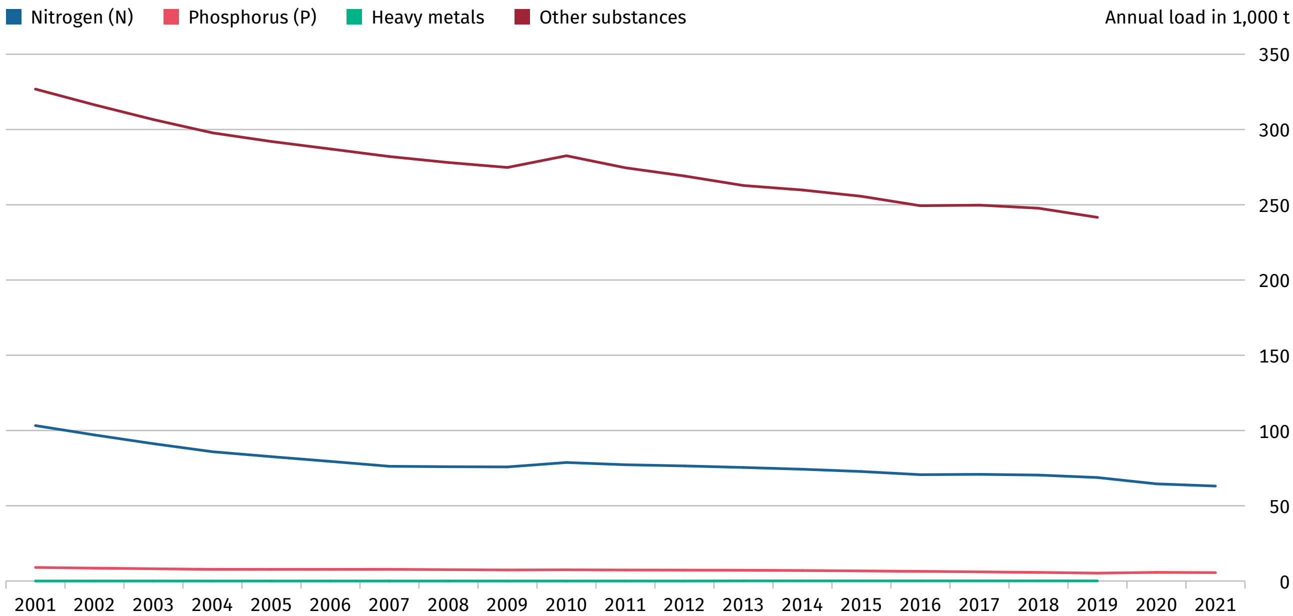
In general, the calculations explained in subchapter 3.2 can be differentiated by data source (EPER, PRTR or water statistics), economic sectors (public wastewater treatment or non-public companies) and type of emission (direct or indirect). Therefore, the results are at first displayed separately for the different data sources, before the final data migration is explained. This part of the report concludes with some considerations relating to the plausibility of our results.

All values displayed in the following represent the estimation results dating to November 2023. There may occur differences in future publications, for instance because of revised source data.

4.1 Water statistics

Water statistics data only provide results for indirect emissions for the public sector but, in contrast to the PRTR, they do cover nearly all the public sewerage facilities in Germany. Figure 4 displays the time series for annual pollutant loads of the public sewerage facilities, including the annual estimation for the missing years as well as estimations on the current end of the time series – namely the years 2020 and 2021 – for nitrogen and phosphorus.

Figure 2:
Time series of pollutant loads in wastewater of the public sewerage facilities calculated based on data from water statistics



4.2 EPER and PRTR

EPER results include both direct and indirect emissions to water, but only for emissions by non-public companies. In contrast, the PRTR comprises both emission types and additionally some information about public sewerage facilities.

Unlike the PRTR, the EPER data needed additional adjustments. Results from the first step, namely the extrapolation of the annual pollutant loads, are displayed in table 5, where the original and the new values are contrasted. Even though the approach of taking coefficients for missing companies and pollutants is arguably simplistic, it nevertheless leads to a harmonising of the EPER and PRTR data for the four different pollutant groups.

Table 5:
Result of the EPER extrapolation calculation to harmonise EPER and PRTR data
Displayed are the annual pollutant loads in 1000 t

	2001	2004
Original value		
Nitrogen (N)	18.195	15.509
Phosphorus (P)	1.288	2.448
Heavy metals	0.260	0.222
Other substances	3,823.569	4,279.989
Estimation results		
Nitrogen (N)	26.895	21.818
Phosphorus (P)	1.904	3.444
Heavy metals	0.384	0.312
Other substances	6,255.344	7,066.959

To finally obtain a complete time series for the years 2001 to 2006, the extrapolated EPER years were linearly interpolated.

Figures 3 and 4 display the combined time series of annual pollutant loads for EPER and PRTR data. Regarding the ‘Other substances’ category in more detail, chlorides (inorganic) and total organic carbon (TOC) are especially predominant in both direct as well as indirect emissions.

Figure 3:
Time series of pollutant loads of nitrogen, phosphorus and heavy metals for wastewater from the economic sectors based on data from EPER and PRTR

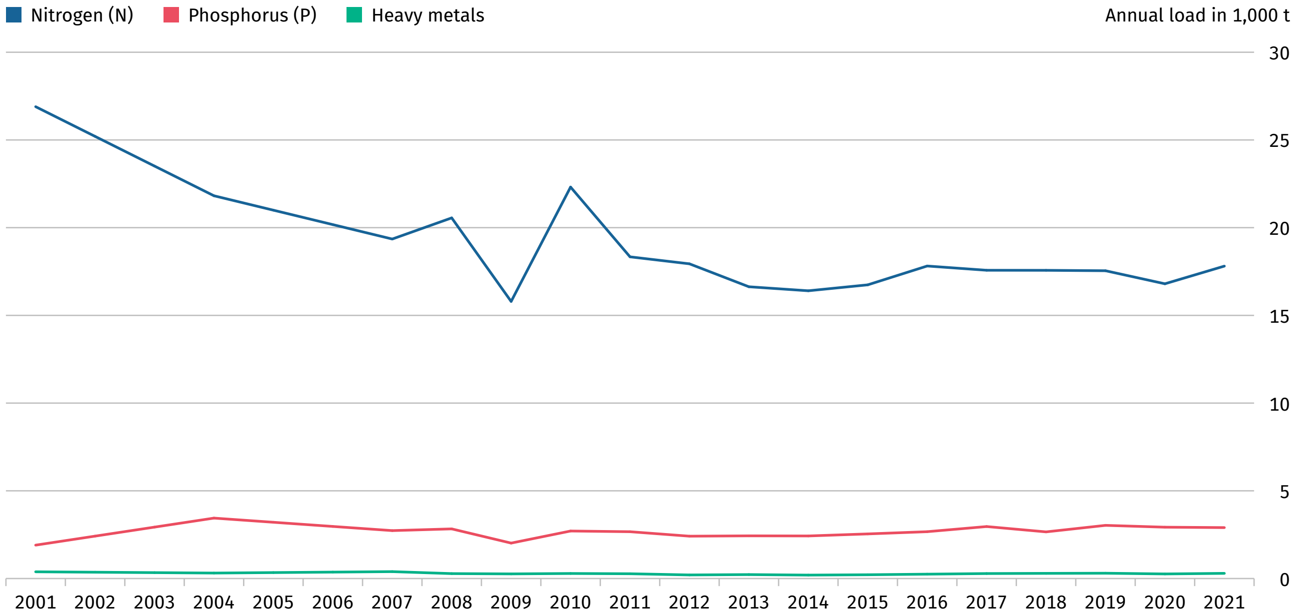
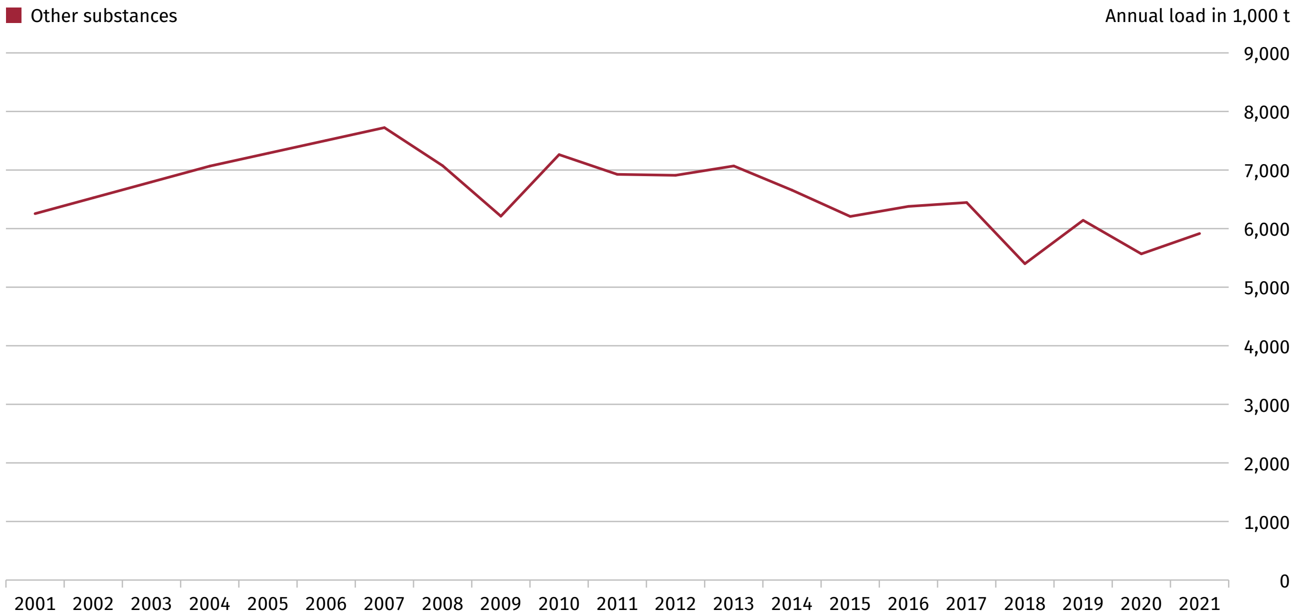


Figure 4:
Time series of pollutant loads of 'Other substances' for wastewater from the economic sectors based on data from EPER and PRTR



4.3 Final data aggregation

To calculate the total emissions according to the structure given in the German material flow accounts and the Eurostat EW-MFA questionnaire, some additional considerations and adjustments were necessary. As the EPER and (later) the PRTR present the only comprehensive sources of pollutants in wastewater for the non-public sector, their data have been adopted without further modification. For the emissions to water by public sewerage facilities, the situation is somewhat more complex: since water statistics provide data on public sewerage facilities from 50 population equivalents while the PRTR covers direct emissions only from 100,000 population equivalents, one would expect the water statistics data to be more detailed and comprehensive. However, PRTR data covers many more types of pollutant (see table 3), namely arsenic and zinc for the heavy metals and around 20 to 30 pollutants belonging to the 'Other substances' category. We therefore decided to use both sources and always select the larger of the two values for each year and pollutant. Table 6 gives an example for the years 2018 and 2019. The finally chosen value in the last column indicates that, for nitrogen and phosphorus, the water statistics data was chosen, whereas the heavy metals and 'Other substances' figures were taken from the EPER and PRTR data. This procedure is also valid for the other years of the time series. This approach seems to us to be consistent, because heavy metals and 'Other substances' are reported more comprehensively in the PRTR. Therefore, heavy metals and 'Other substances' – regarding the public sewerage facilities – do not need annual estimates or estimates at the current end of the time series, because EPER and PRTR data are available or are estimated on an annual basis.

Table 6:
Example of the data selection for the public sewerage facilities for the years 2018 and 2019 for the four categories of pollutant

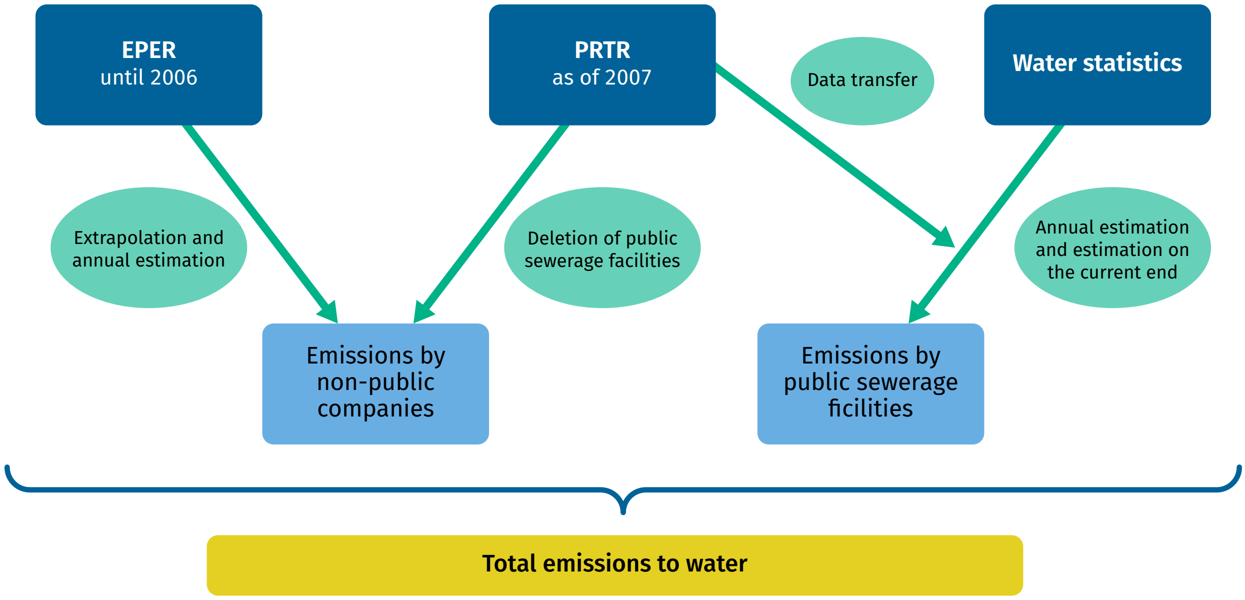
Year	Pollutant	Emissions from public sewerage facilities in 1000t/year		
		Value based on PRTR	Value based on water statistics	Value finally chosen
2018	Nitrogen (N)	33.863	70.387	70.387
	Phosphorus (P)	1.117	5.705	5.705
	Heavy metals	0.187	0.073	0.187
	Other substances	1,002.262	247.722	1,002.262
2019	Nitrogen (N)	32.947	68.752	68.752
	Phosphorus (P)	1.059	5.249	5.249
	Heavy metals	0.202	0.070	0.202
	Other substances	858.095	241.638	858.095

Regarding the loads produced by the occurrence of pollution from heavy metals, another estimation approach is necessary for the years before 2007, because water statistics record these values only as of 2013 and the EPER data do not include public sewerage facilities. Due to the lack of further information and the relatively low levels of heavy metals in contrast to the other pollutants, we decided simply to calculate the average of the years from 2007 and 2021 and transfer this value to the years from 2001 to 2006. We refrained from using a more sophisticated backwards regression, because the heavy metals' values show somewhat larger fluctuations between the years as of 2007.

The final value for the emissions from public wastewater is subsequently added to the values for the non-public emissions from the EPER or PRTR. The latter consists of direct (though excluding the emissions from public sewerage facilities) and indirect emissions.

All data processing and calculation steps are portrayed in the diagram shown in figure 5. Beginning with the three data sources (EPER, PRTR and water statistics), the arrows indicate data flows and the green ovals represent data processing steps. Finally, we obtain data for public and non-public emissions in wastewater which can be summed up to the total emissions to water in Germany.

Figure 5:
Schematic overview of the estimation approach for emissions to water in Germany



Figures 6 and 7 display the time series of the final annual pollutant loads of the emissions to water. The overall trend in particular of phosphorus and heavy metal emissions seems quite steady; also the total nitrogen loads show – apart from a leap in 2010 – a clearly declining trajectory. Regarding the irregularity in 2010, water statistics as well as PRTR data show this increase, even though it is much more distinct in the PRTR data (see figure 2). A more detailed look into the PRTR data reveals that the zigzag course between 2008 and 2011 can be mainly attributed to single companies with high annual pollutant loads. Especially in 2010 one company – belonging to NACE 38.21 'Treatment and disposal of non-hazardous waste' – shows strikingly high values for direct emissions to water, whereas in 2009 the overall level of these emissions is lower than in 2008 or 2011, for example. This anomaly is also visible in the data pertaining to indirect emissions, though less distinct. The overall leap in figure 6 is much less marked, because water statistics data for nitrogen emissions are approximately four times higher than those for nitrogen emissions recorded in either the EPER or PRTR, therefore balancing out the irregularities. In comparison, the 'Other substances' category shows notably stronger fluctuations throughout the years, especially after the replacement of EPER by PRTR data. A possible explanation could be the varying numbers of pollutants covered and, to a smaller extent, the number of reporting companies.

Figure 6:
Time series of the total emissions of nitrogen, phosphorus and heavy metals to water

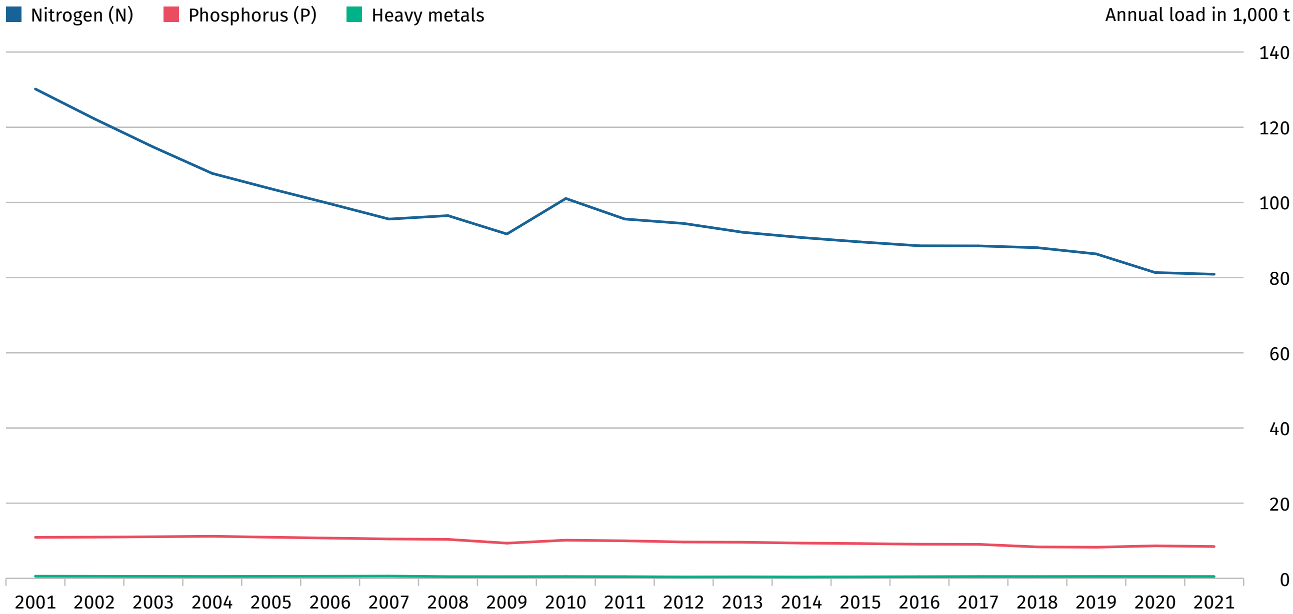
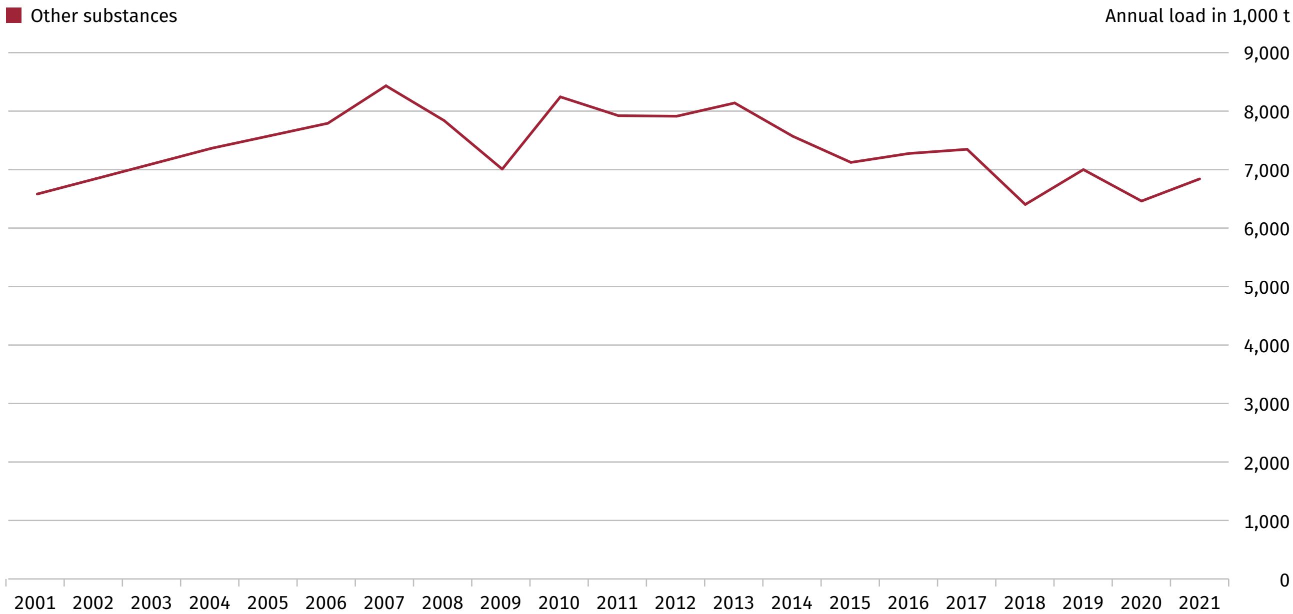


Figure 7:
Time series of the total emissions of 'Other substances' to water



4.4 Validation

In order to validate the new calculation approach, we compared our data on the one hand to our old calculation used for MFA reporting up to 2001 as well as to the estimation conducted by Eurostat and on the other hand to the ‘maximum’ approach presented in section 3.2.3. These comparisons do not aim to – and indeed are not capable of – providing a comprehensive validation of the new estimations’ accuracy but rather serve to check the overall plausibility of the data. A part of the time series of all four estimation approaches is displayed in table 7. The pollutant group ‘Other substances’ was excluded from this comparison because the single pollutants forming this group are not consistent between the different calculation approaches.

Table 7:
Overview of the different estimation approaches for emissions to water, displaying the annual pollutant loads for the years 2000 to 2007
in 1000t

	2000	2001	2002	2003	2004	2005	2006	2007
Eurostat								
Nitrogen	178	166	48	48	48	48	48	48
Phosphorus	12	11	2	2	2	2	2	2
Heavy metals	0	0	0	0	0	0	0	0
Old estimation								
Nitrogen	178	166	-	-	-	-	-	-
Phosphorus	12	11	-	-	-	-	-	-
Heavy metals	-	-	-	-	-	-	-	-
New estimation								
Nitrogen	-	130	122	115	108	104	100	96
Phosphorus	-	11	11	11	11	11	11	10
Heavy metals	-	1	1	1	1	1	1	1
Maximum calculation								
Nitrogen	-	814	-	-	742	-	-	692
Phosphorus	-	81	-	-	74	-	-	69
Heavy metals	-	20	-	-	19	-	-	17

- = no data available

A first glance at the Eurostat estimation reveals a clear leap in the data between 2001 and 2002. This can be traced back to the fact that until 2001, values from our old estimations are available, whereas from 2002 Eurostat implemented its own estimation. Since our new estimations start as of 2001, there is one overlapping year where the old estimates can be compared with the new. The results reveal that total nitrogen loads are reduced by about 22 % – from 166,000 tons in the old calculation to 130,000 tonnes in the new calculation –, whereas phosphorus loads are nearly the same. A comparison with the heavy metals category is not possible, because they were not covered by the old estimation. For the sake of completeness it should be mentioned that the ‘Other substances’ loads in the new estimation are about three times as high as the loads in the old estimation.

The variation for nitrogen may be due to the different data sources – water statistics in the old estimations and EPER or PRTR data in the new estimations – as well as the additional estimations conducted using the old estimation approach (see section 3.2.4). The higher values for the ‘Other substances’ category can be clearly attributed to the higher number of recorded pollutants in the EPER and PRTR data.

The maximum approach serves as an overall validation of the data, creating an upper limit for emissions to water. Compared to the new estimations, all maximum loads of the different pollutants are noticeably above the newly estimated values. Nonetheless, the difference between new estimations and the maximum calculations does not seem to be inexplicably high. In contrast to the new estimation, the maximum calculation is based on the total wastewater volumes recorded in the water statistics, which also include companies with presumably lower amounts of pollutants (e.g. the whole service sector). Beside the service sector it is also unlikely that every company operating in other economic sectors produces wastewater with the maximum legal concentration of pollutants.

4.5 Technical implementation

Besides developing a new estimation for emissions to water, the project also aimed to transfer the calculation into the existing automated compilation framework of the German material flow accounts in SAS. We therefore first transferred all data sources into the existing program, followed by data processing steps and completed with the eventual migration of data.

Calculating the emissions to water in SAS has several advantages: in general, the datasets of EPER and PRTR especially comprise a lot of data, so automation enables calculations to be performed much faster and reduces potential errors. In addition, it facilitates the updating of coefficients – for example for pollutant concentrations – the updating of data sources and possible future adjustments to the calculations. In particular, the estimation of annual data and the estimates at the current end of the time series are more accurate because SAS provides directly applicable procedures for interpolation (such as ‘PROC EXPAND’).

5 Limitations and potential for optimisation

The data sources used here are obviously crucial for creating a set of valid and comprehensive time series governing emissions to water. Regarding comparability and combinability, the optimal solution would be to have one data source for all reporting items and years. In our case this is not possible, because there is no source comprising both public and non-public emissions to water jointly and comprehensively. We have therefore been obliged to combine data from German water statistics and the country’s Environment Agency, the UBA. Naturally, these two sources rely on different data collection methods.

Regarding the comprehensiveness of pollutant recording, the EPER and PRTR data seem to be quite good, but these registers show deficits in their coverage of companies. An example was already given in subchapter 4.3, emphasising the influence of individual companies on the overall time series of the different pollutants. On the other hand, water statistics data capture the majority of public sewerage facilities but, in terms of pollutant content, the contribution to the total of ‘Other substances’ seems especially to be underestimated. We therefore combined both data sources to obtain a more detailed and advanced estimation for emissions from public sewerage facilities.

Nevertheless, water statistics data are still only published every three years, and our annual estimation for interim years on the basis of interpolated pollutant concentrations and wastewater volumes cannot reflect possibly occurring non-linear deviations. Since reporting on EW-MFA is required at t+16 months after the end of the reporting years, additional estimations on the current end of the time series are necessary. These estimations are subject to even greater uncertainties.

We have already established that the data availability in the EPER and PRTR data is not comprehensive, induced by presumably too high threshold values for a legal obligation to record pollutants in the wastewater. Because the EPER and PRTR are the only data sources that cover the relevant pollutants, this is another limitation we have to accept.

A possible approach for further improvement could be to combine pollutant data from the EPER and PRTR with wastewater volumes given in the non-public water statistics publication because the latter includes more surveyed companies. That is somewhat tricky because neither the EPER nor the PRTR provide information on wastewater volumes, which could be used to calculate specific pollutant concentrations. Another approach could be to extrapolate the companies recorded in the EPER and PRTR onto the number recorded in water statistics. In this event, special attention would have to be paid to the fact that data from water statistics presumably record more smaller companies that are likely to be responsible for minor wastewater volumes and pollution loads.

Another approach could be to reimplement the old estimation for additional emission sources described in section 3.2.4 – i.e. direct emissions of private households and farmyard run-off. This would require new and updated data sources to obtain results with sufficient quality and reliability.

Unlike the old one, the new estimation does not aim to calculate pollutant loads separately for different economic sectors. Although this would be an interesting avenue to explore, such a differentiation is at the moment beyond the scope and timescale of this project. Moreover, there is currently no specific reporting requirement for these data.

6 Conclusion

The project ‘Improving Material Flow Accounts’, being part of the Eurostat project 2020-DE_IWSWAMFA, aims to extend the German material flow accounts by incorporating data on emissions to water, including the technical implementation into the existing automated compilation framework.

After detailed examination of potential data sources, we were able to implement a new calculation for emissions to water, providing annual loads for the following pollutants or pollutant groups:

- Total nitrogen
- Total phosphorus
- Heavy metals
- Other substances

Despite the limitations discussed in chapter 5, we are convinced that our new estimations – combining three different data sources – contribute to an increase in the coverage and quality of the reporting on German material flow accounts. These sources, the water statistics as well as the EPER and PRTR register data, are reliable sources of information and provide a credible basis for estimating emissions to water.

In addition, the new estimations also give us the opportunity to extend our data delivery to Eurostat within the framework of the ‘Economy-wide material flow accounts’ (EW-MFA) questionnaire. Even though Eurostat has addressed this gap by carrying out its own estimations in recent years, we believe that our new estimates make an important contribution to methodologically sound reporting at the EU level.

Finally, the estimations of emissions to water were successfully implemented in the ‘Statistical Analysis Software’ (SAS) and embedded into the already existing automated compilation framework of the German material flow accounts. With this step, new data regarding emissions to water can be easily collected, compiled and included in the material flow accounts on an annual basis.

References

BfS. (2023). *'Überwachung der Ableitungen radioaktiver Stoffe aus kerntechnischen Anlagen'.* Bundesamt für Strahlenschutz (BfS) [Federal Office for Radiation Protection]. Webpage: https://www.bfs.de/DE/themen/ion/umwelt/luft-boden/emissionsueberwachung/emissionsueberwachung.html

European Environment Agency. (n.d.). *'Glossary – population equivalent'.* Webpage: https://www.eea.europa.eu/help/glossary/eea-glossary/population-equivalent.

European Environment Agency. (2023). *'Waterbase – Emissions'.* Webpage: https://www.eea.europa.eu/en/datahub/datahubitem-view/5bd950b1-52b9-42f3-b0d7-bf51ff3056b7

Eurostat. (2018). *'Economy-Wide Material Flow Accounts (EW-MFA) – Handbook'.* Luxembourg.

Hilliges, F. (2012). *'Die Qualitätssicherungsverfahren im deutschen Schadstofffreisetzungs- und Verbringungsregister (PRTR) – Bewertung bestehender Instrumente und Implementierung neuer Methoden zur Plausibilitäts- und Kohärenzprüfung'.* University of Rostock.

IKSR (1996). *'Rhein Bestandsaufnahme der Einträge prioritärer Stoffe'.* Internationale Kommission zum Schutz des Rheins. Koblenz.

Jenseit, W., Fendler, R., Mehlhart, G., Klaus, U., Brune, D., Sherif, A. (2001). *'Forschungsbericht Wasser / Abwasser – Bestimmung von Koeffizienten zur Ermittlung von quantitativen und qualitativen Materialflüssen im Wasser- und Abwasserbereich'.* Öko-Institut e. V. Darmstadt.

Jenseit, W., Mehlhart, G., Klaus, U. (2004). *'Bestimmung von Schadstofffrachten im Abwasser von Wirtschaftsbereichen und Privaten Haushalten'.* Öko-Institut e. V. Darmstadt.

Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz. (n.d.). *'LHKW (Trichlorethen und Tetrachlorethen)'.* Webpage: https://www.umwelt.niedersachsen.de/startseite/themen/wasser/grundwasser/grundwasserbericht_niedersachsen/grundwasserbeschaffenheit/guteparameter/erganzungsprogramm_des_nlwkn/lhkw_trichlorethen_und_tetrachlorethen/LHKW-137661.html

United Nations. (2012). *'System of Environmental-Economic Accounting 2012 – Central Framework'.* New York.

Zettl, E., Brondere, C., Kühnl, M., Aigner, J., Geier, F. (2021). *'Analyse des Nutzens und der Wirkung des PRTRs als Instrumentarium zur Vermeidung und Verminderung der Umweltverschmutzung'.* Umweltbundesamt (UBA).