European Commission

JRC TECHNICAL REPORTS

Estimation of domestic and industrial waste emissions to European waters in the 2010s

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2018

Joint Research Centre

EUR 29451 EN

EU Science Hub
https://ec.europa.eu/jrc

JRC113729

EUR 29451 EN

PDF	ISBN 978-92-79-97297-3	ISSN 1831-9424	doi:10.2760/08152
Print	ISBN 978-92-79-97296-6	ISSN 1018-5593	doi:10.2760/204793

Luxembourg: Publications Office of the European Union, 2018

How to cite this report: Vigiak, O., Grizzetti, B., Zanni, M., Dorati, C., Bouraoui, F., Aloe, A., Pistocchi A., *Estimation of domestic and industrial waste emissions to European waters in the 2010s*, EUR 29451 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97297-3 , doi:10.2760/08152, JRC113729.

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Acknowledgements

The work was developed within the JRC under institutional project "Water-Energy-Food-Ecosystems Nexus" supporting the evaluation of the Urban Wastewater Treatment Directive, part of the Evaluation and Fitness Check Roadmap of the European Commission (https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-4989291_en).
Support in developing Annex 2 (Table A2.1) was received from NTUA and CENIA part of the project team from DG Environment led by Wood E&I UK Ltd contract reference 070201/2018/775193/ETU/ENV.C.2 on 'Service request supporting the evaluation of Directive 91/271/EEC concerning urban waste water treatment'.

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Abstract

Estimation of domestic and industrial emissions to the European fresh and marine waters is needed for assessing current ecological status of water bodies and providing inputs to conceptual models of pollutant transport and fate. Regulatory efforts of the European Commission, particularly Urban Waste Water Directive (UWWTD) and Water Framework Directive (WFD) prompted investments in waste treatment, and as a result point source emissions to water bodies have declined. In order to account for these improvements, domestic and industrial emission assessments were to be updated for conditions valid in the 2010s. The aim of this study was to assess the quantity and location of domestic and industrial waste emissions of pollutants in European waters for the 2010s.

Specifically, the pollutants considered in this study were total Nitrogen (N), total Phosphorous (P), and organic pollution as measured by 5-days Biochemical Oxygen Demand (BOD). The spatial resolution and extent of the analysis corresponded to the CCM2 River and Catchment Database for Europe. Pollutants were estimated in terms of mean annual average load (t/y) released in the CCM2 catchments. The reference period for the assessment was set to 2014-2015, although in some cases a longer time period was considered.

The assessment of pollutant loads to waters from domestic and industrial emissions made full use of available European databases created in response to EU regulations. A method was developed to exploit the European datasets and fill in content gaps through alternative sources of information (REP approach). The European datasets allowed pinpointing waste emissions to a much higher spatial and conceptual resolution than before, although some knowledge gaps remained, affecting especially emissions from domestic waste of isolated dwellings, small agglomerations, and industries. Outside EU28, Switzerland and Norway, domestic and industrial emissions were assessed based on population density and national statistics of shares of population served by sewerage treatment and per WWTP treatment level (POP approach).

The comparison between Population Equivalent generated in agglomerations and reported in the UWWTD database with country resident population allowed estimating an equivalence of 1.23 PE per inhabitant, meaning that on average in Europe the contribution of small industries, commercial activities and tourism can be considered about 23% of waste load generated in agglomerations. This information was used to assess population unreported in the UWWTD database because belonging to small, isolated dwellings.

Estimates of total emissions due to domestic waste with REP approach with those from POP approach for 30 countries covered by both methods were in good agreement, with Pearson's correlation coefficient of 0.95 for Nitrogen, 0.94 for Phosphorous and 0.71 for BOD. Yet, important differences emerged when separating emissions by treatment type or pathway, e.g. looking at disconnected, connected not treated or connected and treated shares of domestic waste. The comparison highlighted inconsistencies between the European database and national statistics and it was noted that for some countries national statistics were scant or inconsistent. Thus, while total emissions are comparable, care should be taken when considering each population share independently.

Finally, total pollutant emissions for Europe in 2010s were obtained by merging all available data, using the REP approach and the POP approach estimates to fill in knowledge gaps. In EU28, annual emissions to water from domestic and industrial waste for the 2010s were estimated at 777.6 kt/y of Nitrogen, 126.6 kt/y of Phosphorous and 2,190 kt/y of BOD. The majority of domestic waste is treated in WWTPs, with high adoption rates of tertiary treatment and Phosphorus removal technology, lowering emissions of domestic waste per capita. EU28 IND emissions accounted for 11.3% of N, 6.7% of P and 33.7% of BOD emissions. Waste from population disconnected to sewerage systems or treated with Individual Appropriate Systems (for which only primary treatment was assumed) accounted for 11.2% of Nitrogen,

14.6% of Phosphorous and 19.5% BOD emissions to the environment. However only a part of these emissions would eventually reach freshwater systems, as environmental abatement (not considered in this study) would further reduce them. Conversely, connected not treated population contributed 6.2% of Nitrogen, 7.2% of Phosphorous, and 14.4% of BOD directly discharged to freshwater bodies. Tackling these sources of domestic waste and upgrading primary treatment facilities may further reduce pollution loads discharged in fresh and marine waters.

1 Introduction

Estimation of domestic and industrial emissions to the European fresh and marine waters is needed for assessing current ecological status of water bodies and providing inputs to conceptual models of pollutant transport and fate, such as GREEN (Grizzetti et al. 2012). Previous work estimated mean annual domestic and industrial emissions of Nitrogen (N) and Phosphorus (P) based on population and national wastewater treatment statistics (Grizzetti and Bouraoui, 2006; Bouraoui et al., 2009). These assessments portrayed the European situation in the mid-2000s. Since then, regulatory efforts of the European Commission, particularly Urban Waste Water Directive (UWWTD; EC, 1991) and Water Framework Directive (WFD; EC, 2000) prompted investments in waste treatment, and as a result point source emissions to water bodies have declined (EEA, 2015). In order to account for these improvements, domestic and industrial emission assessments were to be updated for conditions valid in the 2010s.

Estimation of point source emissions required several major steps (Bouraoui et al., 2009): (i) assessment of spatial distribution of population per domestic waste treatment level; (ii) assessment of per capita pollutant emissions; (iii) assessment of pollution removal efficiency per treatment; and (iv) assessment of industrial emissions. Previous assessments were based on population density and national statistics of fractions of population connected to sewerage systems per wastewater treatment level. Since 2010, the European Environment Agency (EEA) collects and publishes data about domestic waste and industrial emissions as reported by EU 28 Member States and other EEA member countries (Norway, Iceland, Switzerland, plus Serbia and Lichtenstein limited to industrial waste), providing detailed information about waste production amount and disposal locations[1]. These data represent a unique source of information of current emissions at high spatial resolution, however their spatial extent does not cover the entire European continent and some waste source gaps might be present where information is not reported.

1.1 Scope of the study

The aim of this study was to assess the quantity and location of domestic and industrial waste emissions of pollutants in European waters for the 2010s. Specifically, the pollutants considered in this study were total Nitrogen (N), total Phosphorous (P), and additionally, organic pollution as measured by 5-days Biochemical Oxygen Demand (BOD). The spatial resolution and extent of the analysis corresponded to the CCM2 River and Catchment Database for Europe (Vogt et al., 2007; 2008), which defines the drainage network of Europe and divides the land into topologically connected catchments[2]. Pollutants were estimated in terms of mean annual average load (t/y) released in the CCM2 catchments. The reference period for the assessment was set to 2014-2015, although in some cases a longer time period was considered.

Domestic emissions were estimated combining two approaches, the first based on population distribution and national statistics on sewerage connection rate and level of treatment (POP approach), and the second based on the data reported by countries in the recently available dataset published by EEA (REP approach). Emissions estimated by the two approaches (POP and REP) were compared to assess differences and reliability of data and methods. The final assessment made full use of the reported data in EEA datasets (REP approach) but filling in data gaps for areas and sources not covered in the EEA datasets through information derived from the POP approach.

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[1] https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-5 (accessed in July 2018)

[2] Since Island is not covered by CCM2, EEA data for Island were not used for the report

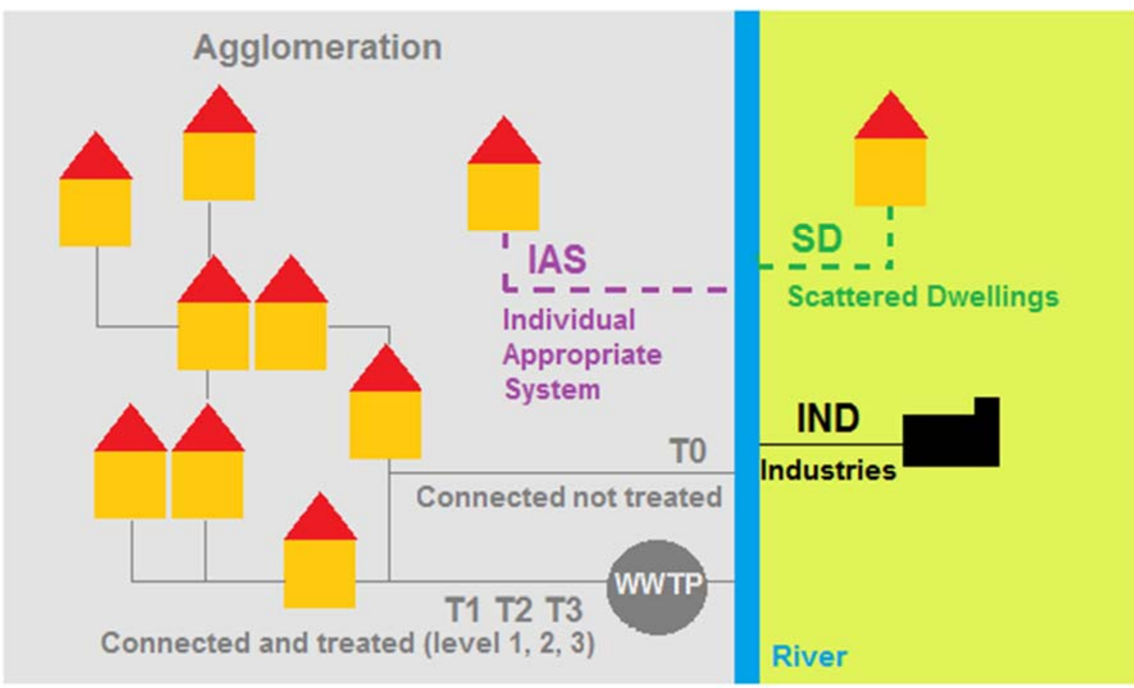
2 Methodology

2.1 Definition of pollution sources and pathways

The assessment of Nitrogen, Phosphorus and BOD to European waters from domestic and industrial waste requires the identification of all sources and pathways of these pollutants in the river basins. Figure 1 provides a schematic representation of the principal sources and pathways considered in this study.

In Europe, most of the domestic waste produced by human settlements and common commercial activities are collected by sewerage systems and treated by waste water treatment plants (WWTPs) before being discharged to the surface water (connected and treated waste). The level of treatment can be primary (T1, mechanical removal), secondary (T2, biological removal), or tertiary (T3, advanced removal). Further, part of tertiary facilities may be equipped with removal systems for Phosphorus (T3P). In some cases waste waters are collected through sewer system but are not treated before being discharged (T0, connected not treated waste). Generally all households in an agglomeration are connected to the sewerage network. However, when this is not possible Individual Appropriate Systems (IAS) can be in place. An IAS collects and treats domestic waste before releasing it to the environment or to a WWTP via truck transport. Small isolated houses (Scattered Dwellings, SD) are not connected to the sewer system but are generally equipped with septic tanks that remove part of the pollution load before the waste infiltrates underground. Finally, some industry facilities can treat and discharge their waste directly into surface waters (IND). In this assessment T0-T3, IAS and SD are considered emissions to waters from domestic waste, while IND represents emissions from industries.

Figure 1. Schematic representation of the principal sources and pathways of Nitrogen, Phosphorus and organic matter (BOD) considered in this study. IAS = Individual Appropriate Systems; SD = Scattered Dwellings; T0 = waste collected in sewerage but not treated; T1-T2-T3: waste water treatment plants discharges differentiated by treatment level; IND = industry emissions.



In terms of pathways, discharges from WWTPs (T1, T2, T3), sewer pipes (T0), and industries (IND) are considered direct emissions to surface water (point sources). Emissions from disconnected sources (IAS and SD) leach underground, where they could contribute locally to the pollution of groundwater, and reach surface water via subsurface pathways (diffuse sources). The pathway of the different sources of pollution influences the residence time and transformation of pollutants in the river basin; longer residence times corresponds to higher pollution abatement in the environment and lower pollution loads to surface waters.

2.2 Assessment of domestic waste emissions to water

Homogeneous data on the quantity and location of all sources of pollution represented in Figure 1 are not available for the whole Europe. Since 2010, the European Environment Agency (EEA) collects and publishes data about domestic waste emissions reported by EU28 Member States and some other EEA member countries (Norway, Iceland, and Switzerland) covering all agglomerations above a minimum size (i.e. population larger than about 2000 persons). These data are collected to monitor progress in the implementation of the EU Urban Waste Water Treatment Directive (EC, 1991), which prescribes specific treatment levels according to the size of agglomerations and the sensitivity to eutrophication problems of the receiving waters. The last released dataset (UWWTD database; EEA, 2017) refers to data reported in 2014-2015. Based on this information, point emissions of Nitrogen, Phosphorus and organic matter (BOD) can be estimated (called REP approach in this assessment).

The UWWTD database is a very detailed source of information on current emissions. However, domestic waste emissions from scattered dwellings and settlements with less than 2000 persons are not included. In addition, the spatial extent of the dataset does not cover the entire European continent and some gaps might be present for countries that do not report through the EEA.

An alternative method to estimate domestic waste emissions (Grizzetti and Bouraoui, 2006; Bouraoui et al., 2009) is not based on reported discharges but makes use of national statistics and data on population. It considers national statistics of the level of treatment of waste water and population density to spatially distribute the population per treatment level across each country (called POP approach in this assessment).

The present European assessment of domestic waste emissions of Nitrogen, Phosphorus and organic matter (BOD) was based on the data reported in UWWTD database (REP approach) combined with estimations based on the national population data (POP approach). The assessment of domestic waste involved several steps, which are presented in the following subsections:

1. Assessment of the spatial distribution of annual domestic waste (LOCATION)
2. Assessment of the pollution loads (QUANTITY)
3. Level of treatment (ABATEMENT)

2.2.1 Spatial distribution of annual domestic waste (LOCATION)

2.2.1.1 Estimations based on population distribution (POP approach)

The population approach is based on national statistics of domestic waste treatment coupled with the spatial distribution of population density. The percentage population connected to sewerage system and receiving wastewater treatment level were derived from national statistics (Table 1).

The main source of information was Eurostat (2018a), which reports several statistics with regards to wastewater collection and treatment. Population shares reported in Table 1 are based on (Eurostat, 2018a): 'Urban wastewater collecting system' (Collected in sewer %); 'Independent wastewater treatment – total' (IAS, %); 'Urban and other wastewater treatment plants - primary treatment' (1ary treatment, %); 'Urban and other wastewater treatment plants - secondary treatment' (2ary treatment, %); 'Urban and other wastewater treatment plants - tertiary treatment' (3ary treatment, %). In some cases the distribution in 1ary, 2ary or 3ary treatment plants was not reported in Eurostat (2018a), and was derived from another dataset (Eurostat, 2018b).

From these five main statistics, derived shares of population used in the analysis were defined as: (a) population whose waste is collected but not treated (Pop_0 = Collected in sewer – sum of 1ary, 2ary and 3ary treatments, %); (b) Disconnected population (DISC), i.e. population whose waste is not collected in sewers (DISC = 100 - Collected in sewer, %); (c) Scattered Dwellings (SD), i.e. small, sparsely distributed homesteads, equal to the share of disconnected population that is not treated with IAS (SD = DISC – IAS, %). Small inconsistencies in the national statistics were identified. For example, IAS data were sometimes unreported or larger than DISC; Pop_0 did not always match Eurostat (2018a) 'Percentage of resident population not connected to urban and other wastewater treatment plants' statistics. The inconsistencies were addressed maintaining information about collected and treated shares, while adjusting not collected or not treated shares. All country population shares applied in this study are reported in Annex 1.

The statistics inconsistencies indicate the presence of conceptual uncertainty in defining population shares, especially Pop_0 and DISC. Statistics from countries not reported in Eurostat may be even more uncertain, as international reporting sources indicate sometimes discordant figures (Sato et al., 2013). Caution should be exerted especially for statistics reported for Albania, Moldova, and Russian Federation.

The 1 km^2 raster grid of Global Human Settlement (GHS) population of 2015 (CIESIN, 2015) was used to define population density (inhabitants/km^2). Population was allocated to wastewater treatment shares according to population density assuming that most densely populated areas would benefit of the best nationally available technology, and vice versa the least populated areas would not be connected to sewerage systems (Fig. 2). While this may not hold true across all Europe, the assumption finds general anecdotal confirmation in a qualitative survey about treatment levels in use in large European towns in the 1990s (Annex 2). Four population density thresholds per country were identified based on the national cumulative population density distribution and national treatment statistics. After applying

Table 1. Percentage of population connected to sewers and to wastewater treatment levels adopted in the POP approach. Reference year was 2015, or closest possible (indicated in Data Year). Further explanations in the text.

Country	Data year	Collected sewer (%)	IAS (%)	1 ary treatment (%)	2 ary treatment (%)	3 ary treatment (%)	Source
Albania	2015	19.0	NA	11.0	7.0	1.0	Eurostat (2018a)
Austria	2014	95.0	5.0	0.0	1.2	93.8	Eurostat (2018a)
Belarus(1)	2015	91.1	NA	25.7	64.7	0.0	JMP (2017); NSCRB (2018)
Belgium	2013	91.4	8.6	0.0	10.8	73.4	Eurostat (2018a)

Bosnia Herzegovina	2013	35.2	NA	0.1	1.2	0.6	Eurostat (2018a)
Bulgaria	2015	75.5	24.5	1.7	16.9	43.8	Eurostat (2018a)
Croatia	2015	54.6	45.4	16.0	35.9	1.0	Eurostat (2018a)
Cyprus	2005	29.8	70.2	0.0	4.7	25.1	Eurostat (2018a; 2018b)
Czech Republic	2015	85.2	2.4	0.2	6.9	73.9	Eurostat (2018a)
Denmark	2014	91.0	9.0	0.0	2.0	89.0	Eurostat (2018a)
Estonia	2014	83.0	5.0	0.0	5.0	78.0	Eurostat (2018a)
Finland	2013	83.0	17.0	0.0	0.0	83.0	Eurostat (2018a)
France	2014	82.1	18.0	0.1	14.3	66.1	Eurostat (2018a)
Georgia	2015	44.2	23.4	28.6	3.3	0.2	NSOG (2018)
Germany	2013	96.2	3.2	0.0	2.5	92.9	Eurostat (2018a)
Greece	2014	92.9	0.0	0.0	3.6	89.3	Eurostat (2018a)
Hungary	2015	78.8	NA	0.1	12.2	64.6	Eurostat (2018a)
Iceland	2010	91.0	7.0	65.0	0.0	1.0	OECD (2018)
Ireland	2014	69.0	31.0	0.0	47.0	18.0	Eurostat (2018a)
Italy	2015	94.0[$]	NA	2.9	18.7	40.9	Eurostat (2018a)
Kosovo*	2015	54.3	0.0	0.0	0.6	0.0	Eurostat (2018a)
Latvia	2013	71.1	28.9	3.7	50.0	17.2	Eurostat (2018a)
Lithuania	2015	72.5	NA	0.1	6.9	65.4	Eurostat (2018a)
Luxembourg	2015	98.2	1.8	1.8	25.2	71.2	Eurostat (2018a)
Macedonia, FYR[(1)]	2012	60.0	NA	6.5	6.5	0.0	World Bank (2015c)
Malta	2014	98.6	0.0	6.4	92.2	0	Eurostat (2018a)
Moldova[(1)]	2013	38.0	NA	12.0	12.0	0.0	World Bank (2015a)
Montenegro[(1)]	2012	43.0	NA	9.0	9.0	0.0	World Bank (2015b)
Netherlands	2015	99.4	0.6	0.0	1.0	98.4	Eurostat (2018a)
Norway	2015	86.2	13.8	18.1	1.6	64.1	Eurostat (2018a)
Poland	2015	72.6	NA	0.0	13.7	58.9	Eurostat (2018a)
Portugal	2009	81.3	5.0[#]	3.6	39.4	16.4	Eurostat (2018a)
Romania	2015	47.8	1.9	6.3	14.7	24.9	Eurostat (2018a)
Russian Fed.	2000	75.0	NA	2.0	54.0	1.0	Williams et al., 2012
Serbia	2015	58.7	NA	1.3	8.7	1.9	Eurostat (2018a)
Slovenia	2015	62.6	35.2	0.0	30.5	27.1	Eurostat (2018a)
Slovak Republic	2015	65.2	NA	0.1	33.0	31.4	Eurostat (2018a; 2018b)
Spain	2014	97.2	1.5	1.7	23.9	69.0	Eurostat (2018a)
Sweden	2014	87.0	13.0	0.0	4.0	83.0	Eurostat (2018a)
Switzerland	2013	98.3	1.7	0.0	11.0	87.0	Eurostat (2018a)
Turkey	2013	87.0	0.0	20.9	24.8	18.4	Eurostat (2018a)
Ukraine[(2)]	2015	52.7	NA	16.2	16.2	0.0	JMP (2017); SSSU (2018)
United Kingdom	2014	100.0	NA	0.0	43.0	57.0	Eurostat (2018a)

* under United Nations Security Council Resolution 1244/99

[(1)] World Bank reports indicate connected rate and percentage of treated waste but not division between treatment levels. In this case half of the rate was attributed to primary and half to secondary level

[(2)] Connected rate was derived from JMP (2018); attribution to treatment levels was based on national statistics

[$] IT data for Collected in sewer from year 2009

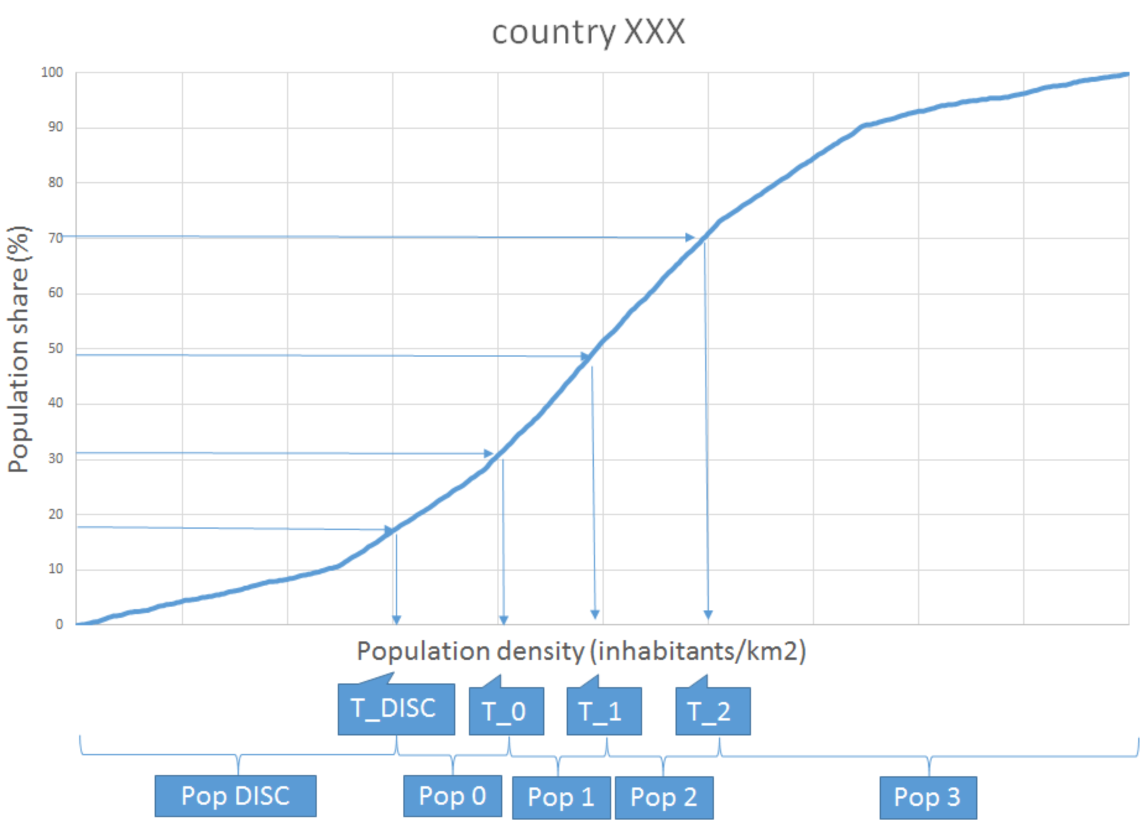
[#] PT data for IAS of year 2005

the density thresholds, the mean population density per treatment and per CCM2 catchment was calculated. The number of inhabitants per treatment and per catchment was obtained by multiplying the catchment mean by the catchment area (km^2). The flow charts of the procedure and density thresholds set for 2015 are reported in Annex 2.

Through this procedure (Fig. 2), population was spatially partitioned into:

1. Population that is not connected to sewer systems (Pop_DISC: density < T_DISC).
2. Population that is connected to sewer system but whose waste is not treated (Pop_0: T_DISC >= density < T_0)
3. Population that is connected to sewer system and whose waste is treated at primary (Pop_1: T_0 >= density < T_1), secondary (Pop_2: T_1 >= density < T_2), or tertiary level (Pop_3: density >= T_2).

Figure 2. Setting of country density thresholds was based on cumulative population density distribution and national statistics, and allowed defining country shares of disconnected population (Pop_DISC), population connected but not treated (Pop_0), connected and treated at primary level (Pop_1), connected and treated at secondary level (Pop_2), connected and treated at tertiary level (Pop_3).



A final check consisted of summing inhabitants per country and treatment level to see if proportions respected the official national statistics. Deviations of allocated and national population shares were less than 0.35% for more than 90% of cases. The largest negative deviation was -3% for tertiary treatment in Turkey, and +3% of primary treatment in Georgia. Within EU28, the largest deviation was +1.2% population allocated to tertiary treatment in Luxemburg. These differences are due to errors in allocating a CCM2 catchment to a single state along country borders.

Pop_DISC was divided in the two fractions, IAS and SD based on the ratio IAS/DISC (from Table 1; Pop_IAS =IAS/DISC * Pop_DISC; Pop_SD =(1-IAS/DISC)*Pop_DISC). The spatial distribution of Pop_DISC depends on the lowest density threshold set for disconnected population (T_DISC, Fig. 2), thus Pop_IAS and Pop_SD share the same spatial distribution.

2.2.1.2 Estimations based on reported data (REP approach)

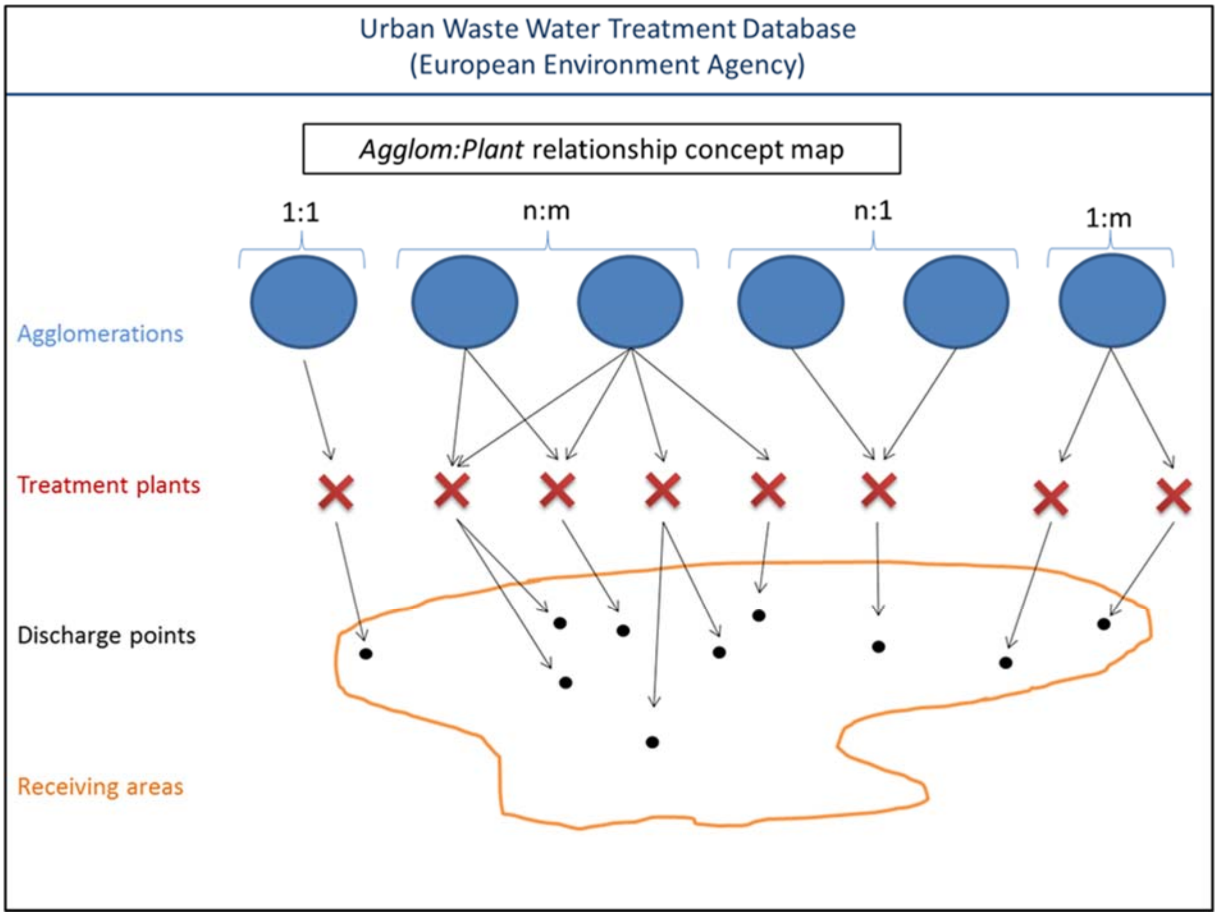
For this assessment the UWWTD database v6, reporting data for 2014 (EEA, 2017), was used. The UWWTD database reports domestic waste emitted by agglomerations larger than 2000 Person Equivalent (PE) in the 28 EC Member States plus Iceland, Norway and Switzerland. A Person Equivalent is defined as the amount of waste that equals to 60 g per day of BOD. The database reports waste loads generated by agglomerations, to which WWTP loads are transferred to, WWTP treatment levels, and location of WWTP discharge points. All loads are reported in terms of PE. To a first approximation, it can be assumed that 1 PE is equivalent to one person. However, besides waste generated by resident population, PE loads reported in the database comprise also commercial, industrial, or tourism waste that is produced in the agglomerations.

The database is composed of several tables that portray the complex transfers between agglomerations, WWTPs, and discharge points. The waste load generated in agglomerations may be transferred to WWTPs, to IAS, or discharged without treatment. One agglomeration can be served by more than one WWTP and one WWTP may serve more agglomerations, i.e. transfers from agglomerations to WWTPs can vary from 1:1 to m:n (many to many). Finally, a WWTP may have one or more discharge points (Fig. 3).

In the database, some missing data and errors, for example in geographic coordinates, were detected. Further, there were several inconsistencies between waste loads generated by agglomerations, transferred to WWTPs, treated, and ultimately transferred to discharge points (Amparore, 2012). Thus, the UWWTD database was not used as reported but it was revised, filling in the missing information and reducing inconsistencies by tracking records through the database structure (following Amparore, 2012), with the aim of preserving the waste load generated by agglomerations and tracking its fate to IAS, WWTPs, and discharge points. While this may have reduced database inconsistencies, it may also have inadvertently generated errors, as assumptions had to be made when addressing each inconsistency/error type. This may be particularly true for Croatia, for which no information on distribution of generated waste is reported and for which mean statistics for neighbour Slovenia were used instead. Thus Croatia results should be considered approximations only. Annex 3 reports the inconsistencies that were detected and the rules applied to address them.

The revision allowed to attribute PE generated in agglomerations (PE_GEN) to IAS or WWTPs discharge points. Waste load treated through IAS (PE_IAS) was equalled to the share of load transferred from agglomerations to IAS (TO_IAS; table 2) less the waste load transferred from agglomerations to WWTPs by truck (IAS_to_WWTP; Fig. 4, Table 2). In total, about 628 M PE were generated in the 30 countries comprised in the UWWTD database (PE_GEN); of this waste about 2.3% was not treated (PE_0), 1.8% was treated in IAS (PE_IAS), and 96% was connected and treated in UWWTPS (PE_WWTP).

Figure 3. The UWWTD database structure (from Amparore, 2012).

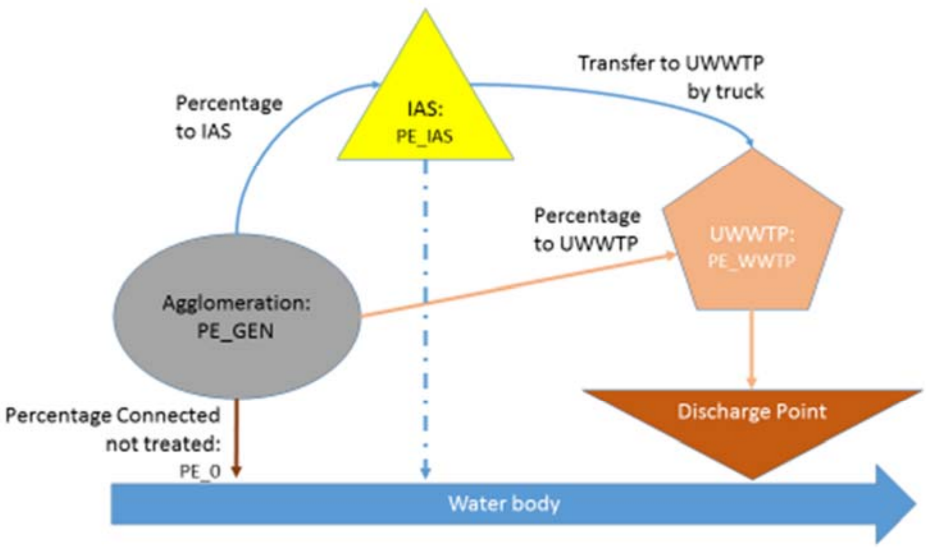


As no information about treatment and location of IAS is given in the database, IAS waste load was considered to receive primary treatment only, and discharged at the agglomeration coordinates. IAS were assumed to discharge in the ground and not directly in the stream network (diffuse source). Waste generated in agglomeration but not treated (PE_0) was considered to be discharged directly to the stream network at the agglomeration location, less a 10% abatement that occurs in the sewerage system (Morée et al., 2013). Waste load transferred to WWTPs was reduced according to WWTP treatment level, and emitted in the main reach of the WWTP discharge point catchment. When one WWTP had more than one discharge point, WWTP emissions were divided among discharge points assuming that larger portions of waste would be discharged to larger rivers/streams. The mean annual flow of receiving reaches as estimated with a simple Budyko water yield estimation (Pistocchi et al., in preparation) was used to define each discharge point receiving fraction.

Table 2. Country total PE generated in agglomerations (PE_GEN) but not treated (PE_0), destined to Individual Appropriate Systems (To_IAS), and from these transferred to WWTPs (IAS_to_UWWTP), treated in IAS (PE_IAS), or treated in WWTPS (PE_UWWTP) from the revision of UWWTD database adopted in this study.

Country	PE_GEN	To_IAS	IAS_to_ WWTPS	PE_0	PE_IAS	PE_WWTP
Austria	20434531	138055	137980	0	75	20426256
Belgium	9243830	0	0	23063	0	9212547
Bulgaria	8117546	531	4846	1302561	525	6785812
Croatia	5026227	258309	17	366432	258292	4398496
Cyprus	995000	16219	1229	240545	14990	739358
Czech Republic	7750440	529902	12	0	529890	7205872
Denmark	11612545	0	0	0	0	11577853
Estonia	1659559	41945	41429	8790	516	1610713
Finland	5373100	0	0	0	0	5444050
France	72466152	0	0	0	0	72443721
Germany	109911631	2026718	759807	0	1266911	109150371
Greece	11792198	1221689	79242	0	1142447	10653960
Hungary	11880518	1527139	4	0	1527139	10329621
Ireland	5255765	262788	0	0	262788	5255765
Italy	77975735	3456467	2677	577726	345790	73743067
Latvia	1572911	85728	1	0	85727	1499719
Lithuania	2665020	128663	0	0	128663	2539160
Luxembourg	625031	4479	2	0	4477	636115
Malta	513001	0	0	0	0	513001
Netherlands	18229830	0	0	0	0	17995880
Norway	5184968	48990	1	199572	48989	5305912
Poland	38536550	3350337	315275 0	233970	197587	38194838
Portugal	12105560	0	0	6090	0	12099993
Romania	23423685	152455	89419	10549977	63036	12823465
Slovak Republic	4656291	766082	1531	14424	764551	3867204
Slovenia	1472002	92197	0	126437	92197	1254677
Spain	64483948	937716	1	883809	937715	62676183
Sweden	12551265	0	0	0	0	12551265
Switzerland	10976762	1491	1	212974	1490	10882593
United Kingdom	70973675	371221	78757	0	292464	70820863

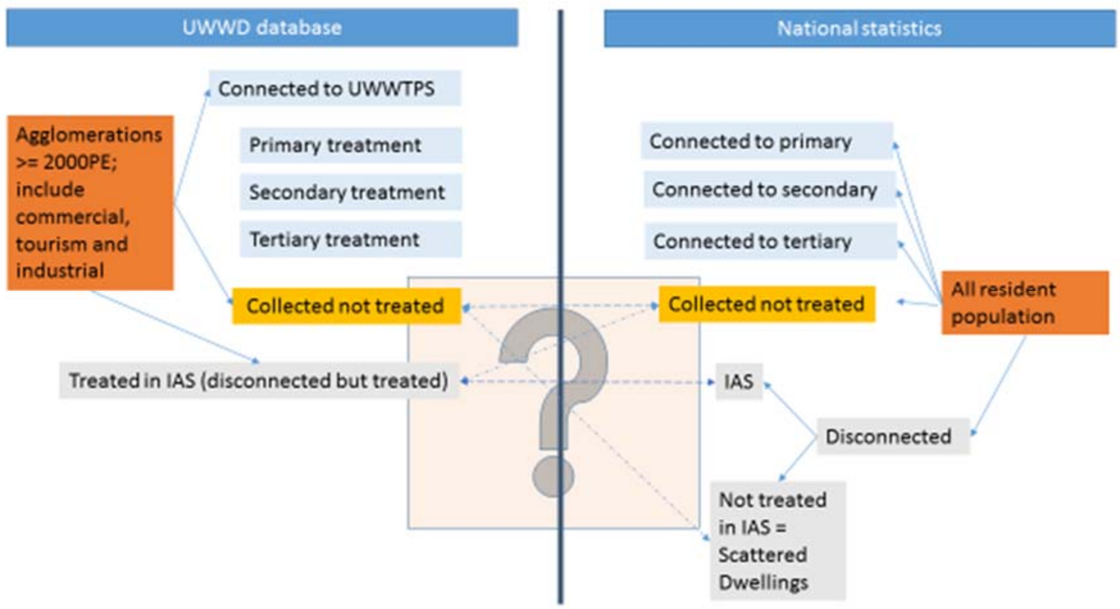
Figure 4. Waste paths from agglomerations to stream network built using the UWWTD database. Waste generated in agglomerations can follow three routes: (i) to WWTPs, (ii) to Individual Appropriate Systems (IAS), and (iii) collected in sewerage systems but not treated. Locations of WWTP discharge points is provided in the database. IAS and connected not treated (T0) waste was assumed to be discharged at the agglomeration catchment.



2.2.1.3 Comparison and merging of the two data sources to assess domestic waste

The UWWTD database does not comprise all domestic waste sources, because it does not report waste from agglomerations below 2000 PE if the waste is not treated. Conversely, any waste connected to a WWTP should be reported in the database, regardless of the agglomeration size. Thus, part of the population that is disconnected from sewerage systems (part of Pop_DISC) or possibly served by sewerage but not treated in small agglomerations (part of Pop_0; Fig. 5) may not be reported. To fill in this source gap and avoid losing domestic waste, it was necessary to estimate which quota of population may not be reported in the UWWTD database (called herein “residual population”, Pop_RES). This was done considering the estimations based on the population distribution and national statistics (POP approach). However, this was complicated by (i) differences in reported units, as the UWWTD database reports PE while the POP approach is based on inhabitants; and (ii) the uncertainty in reported shares of Pop_DISC and Pop_0 highlighted in POP approach section.

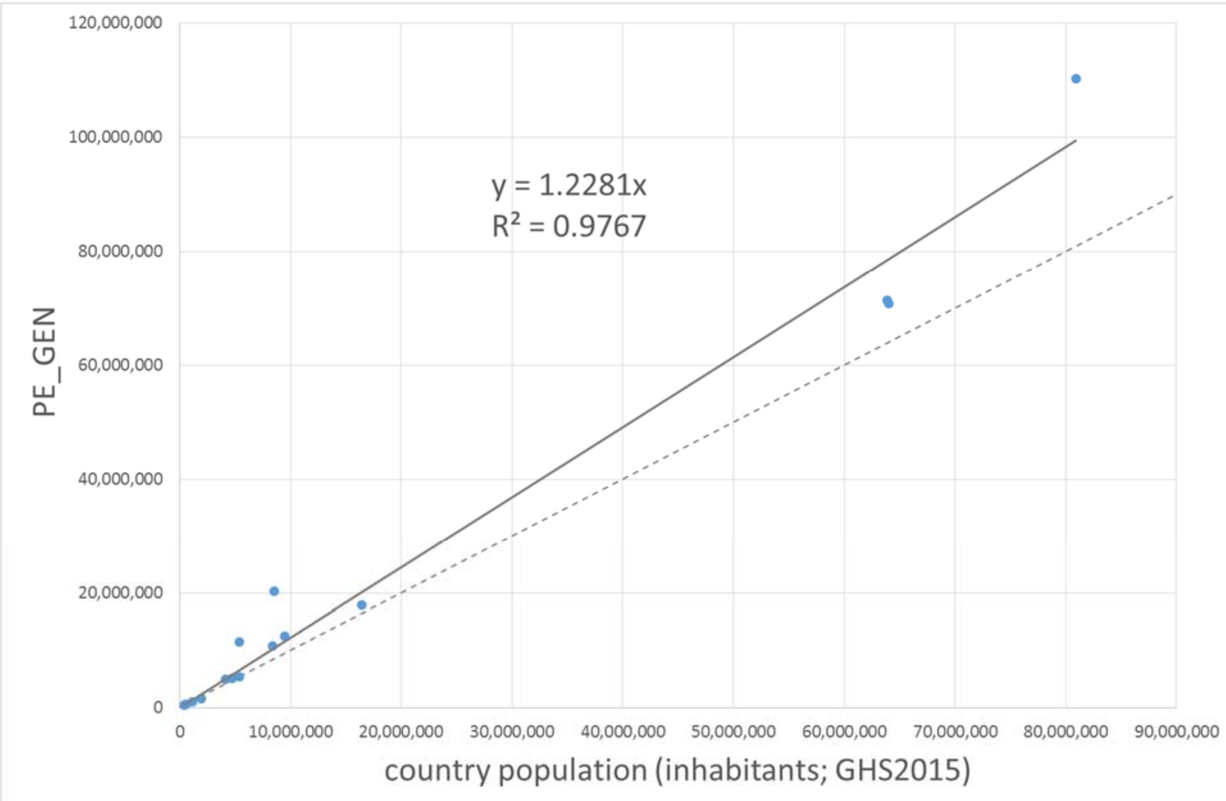
Figure 5. Conceptual comparison between domestic waste approaches. The REP approach was based on UWWTD database, and the POP approach was based on national population statistics. Most of the uncertainty surrounds the potential gaps for coverage of domestic waste in untreated or disconnected population shares.



The relationship between PE reported in the database (PE_GEN) and inhabitants (resident population) needed be better understood to allow for a meaningful comparison and merging of the two approaches. Theoretically, missing population in the UWWTD database would be minimal in countries where disconnected (Pop_DISC) or connected but not treated (Pop_0) population is nil or very low. Of the 30 countries included in the UWWTD database, 15 reported at least 98% of population as connected and treated (Table 1). The country ratio between PE_GEN and resident population (inhabitants) for these 15 countries ranged from 0.8 to 2.4 (median 1.12). Despite the variability, the scatter plot indicated a strong linear relationship between PE and inhabitants (regression equation: PE_GEN = 1.23 inhabitant; $R2 = 0.98$; sample size = 15; Fig. 6). Further search for trends of PE_GEN/Population rate versus gross domestic product (GDP) or fraction of rural population yielded no significant improvement (Annex 4). When enlarging the sample to all 30 countries of the UWWTD database, the linear relationship was confirmed and the ratio only slightly increased to 1.24. Given the uncertainty in the amount of unreported population in countries with higher fractions of disconnected or not treated population, the 15 country sample PE_GEN/population rate of 1.23 was adopted to transform PE into resident population and vice versa. We refer to inhabitants derived from PE as Population Resident Equivalents (PRE, inhabitants), where 1 PRE = 1 PE / 1.23.

The interpretation of this rate is that on average across Europe the contribution of commercial, industrial and tourism emissions to domestic waste on top of resident population can be considered around 23%. This figure is higher than a global average of 15% (Morée et al., 2013) but seems reasonable for industrialized countries, and especially for urban population.

Figure 6. Scatter plot of country total PE (generated in agglomerations; PE_GEN) reported in the UWWTD database against population (inhabitants, estimated with GHS2015) for 15 countries covered by UWWTD database whose population of connected and treated waste was equal or higher than 98%. Dashed line indicates 1:1 relationship; the continuous line indicates the linear regression (PE = 1.23 Population, R2 = 0.98, sample size = 15).



Once the PE/PRE equivalence of 1.23 was established, it was possible to estimate country population that was not accounted for in the UWWTD database (Pop_RES). Figure 7 shows a conceptual scheme of the procedure. First of all, country total PE_GEN reported in the UWWTD database were transformed into the equivalent resident population (PRE) and compared to total population (PopTot; from GHS2015). Pop_RES was the difference between total population (PopTot) and the estimated inhabitants reported in the UWWTD database (PRE). If the total population was lower than estimated PRE, Pop_RES was nil (case A in Fig 7).

Pop_RES was taken and spatially distributed as a portion of the population that, according to national statistics, was either disconnected (Pop_DISC) or, when this was insufficient to cover the gap, connected not treated (Pop_0). When Pop_RES was less than disconnected population (Pop_DISC), Pop_RES was taken as the fraction Pop_RES/Pop_DISC (up to one; case C in Figure 7). All this fraction was considered belonging to scattered dwellings (Pop_RES_SD). When Pop_RES was larger than Pop_DISC, then after allocating Pop_RES_SD equal to Pop_DISC, the remaining portion of Pop_RES was taken and distributed as a fraction of connected not treated population (Pop_RES_0; case D in Figure 7). Finally, there could be cases where Pop_RES was larger than the sum of Pop_DISC and Pop_0 (case E in Figure 7). In these cases, all Pop_DISC was considered Pop_RES_SD, all Pop_0 was considered Pop_RES_0, but there was no further attempt to fill the remaining estimated population gap, and the final Pop_RES allocated to the country was lower than the population gap initially estimated.

Figure 7. Assessment of population unreported in the UWWTD database by comparing with resident population. PE: total generated PE per country. PRE: Population Resident Equivalent (=PE/1.23).

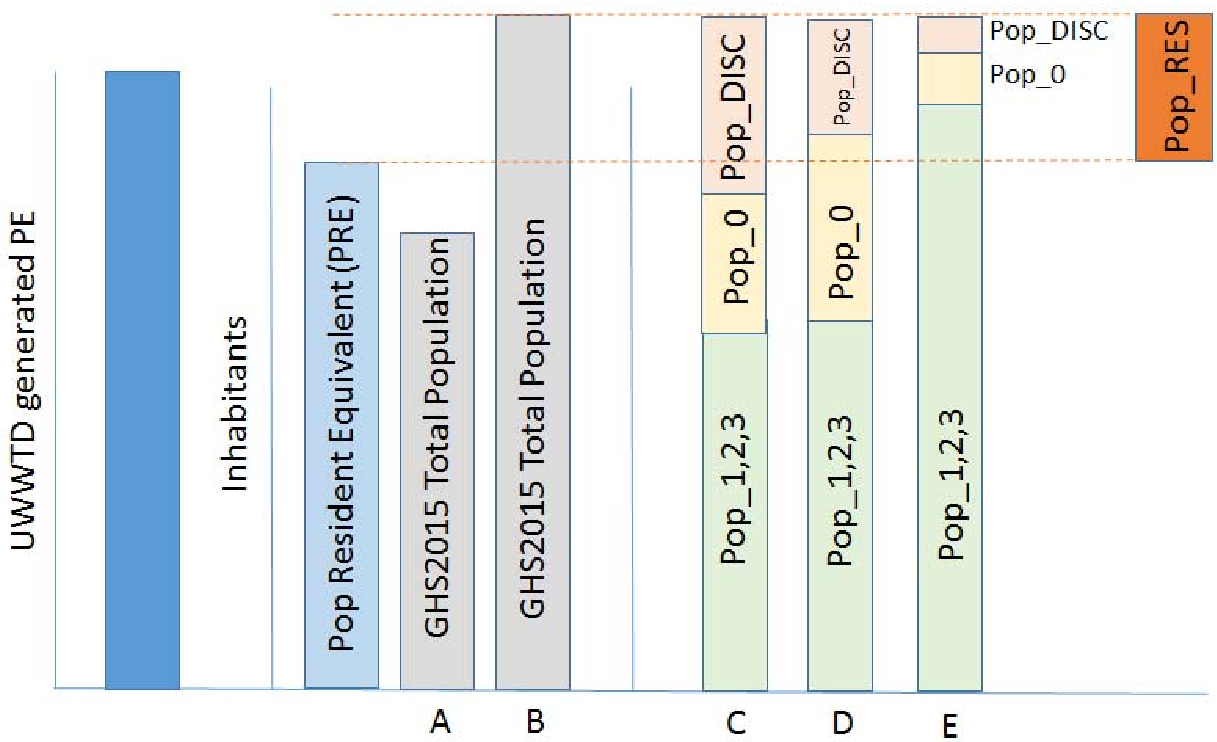
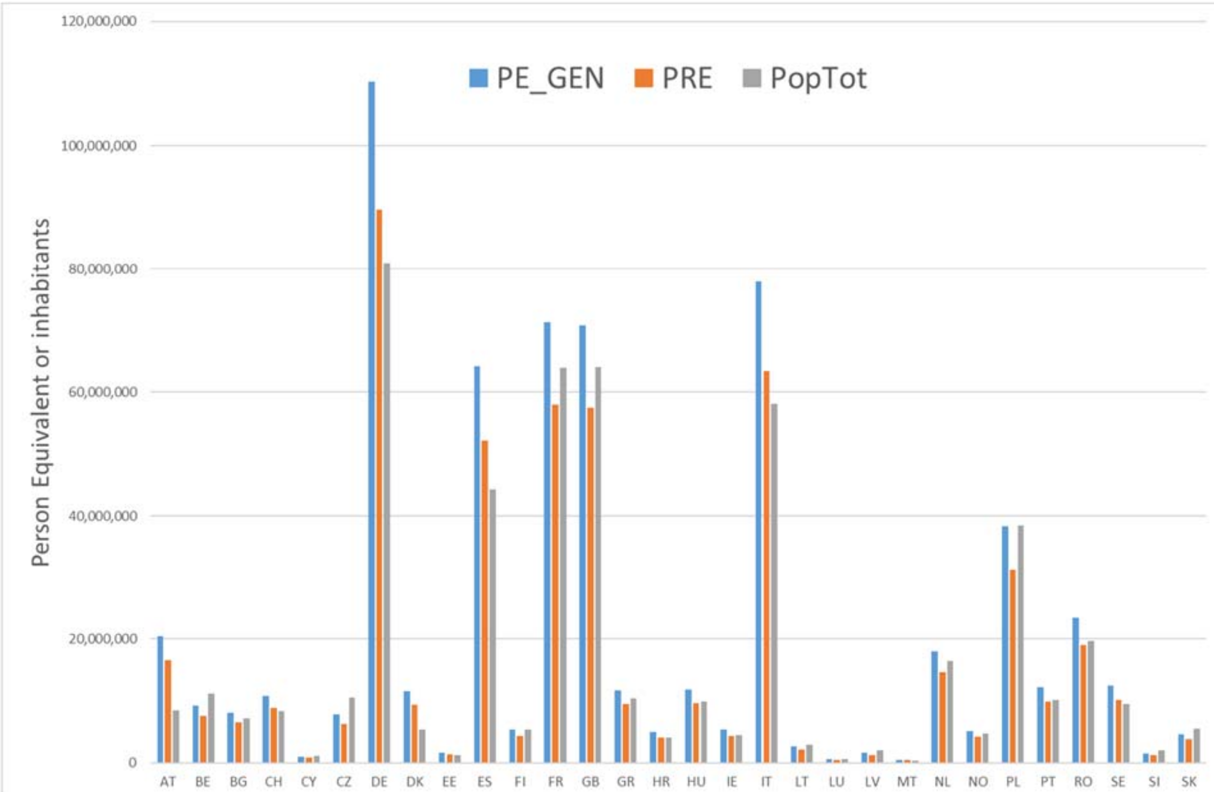


Figure 8 shows country total PE_GEN, their corresponding PRE and GHS2015 population (PopTot). In some countries (AT, CH, DE, DK, EE, ES, IT, MT, and SE), PRE exceeded population thus Pop_RES was nil. In other cases, GHS2015 population exceeded PE_GEN (BE, CY, CZ, LT, LV, PL, SI, and SK); in these countries Pop_RES amounted to 16 - 42% of population, and was a considerable source of domestic waste in addition to what reported in the UWWTD database. Finally, in the remaining countries (BG, FI, FR, GB, GR, HR, HU, IE, LU, NL, NO, PT, RO) total PE_GEN were larger than population, but the corresponding PRE were lower than population. In these cases, the median Pop_RES was 3% of population, but arrived to account for 9% of FR, 11% of NO, and 17% of FI population. In total, Pop_RES amounted to about 25 M inhabitants. Estimated Pop_RES, Pop_RES_SD, and Pop_RES_0 per country are in Annex 5.

Figure 8. Comparison between generated Person Equivalent as reported in the UWWTD database (PE_GEN), the equivalent estimated resident population (PRE, = PE/1.23, inhabitants), and total population estimated from GHS2015 (PopTot, inhabitants). The difference of PopTot minus PRE, when positive, was considered as resident population not accounted for in the UWWTD database because belonging to small and isolated dwellings (agglomerations <2000PE; Pop_RES).



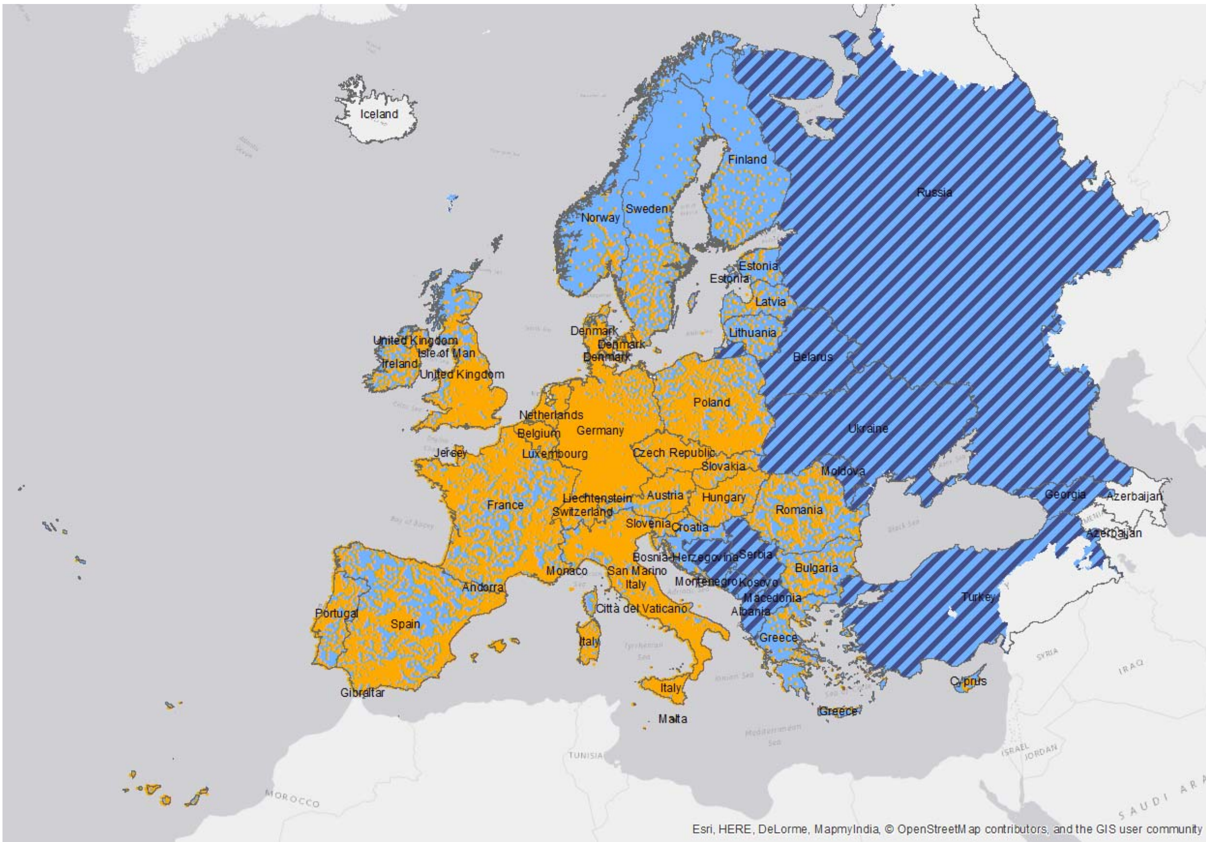
2.2.1.4 Overall assessment of domestic waste

Since the UWWTD database does not report data for all European countries, different approaches to estimate domestic waste sources were considered (Fig. 9):

— Treated loads: in regions covered by the UWWTD database, treated load was estimated with the UWWTD database and attributed to discharge point locations. For countries not covered by the UWWTD database, treated waste was estimated with Pop_1, Pop_2 and Pop_3 assessed with POP approach, and emissions were distributed according to catchment population density.

— Disconnected and connected not treated domestic loads: in regions covered by the UWWTD database, PE_IAS and PE_0 reported in the UWWTD database were attributed at agglomeration coordinates. Additionally, population pertaining to small agglomerations (Pop_RES) were distributed according to POP approach (Pop_RES_SD and Pop_RES_0, as described above). For countries not covered by the UWWTD database, the analogues from POP approach (Pop_SD, Pop_IAS, and Pop_0) were used.

Figure 9. Data coverage of domestic waste used in the study. Blue background indicates data coverage for population statistics (POP approach). Orange dots indicate emission points estimated from the UWWTD database, covering EU28, Norway and Switzerland. Stripes indicate regions for which the POP approach was used to assess domestic waste.



2.2.2 Domestic pollutants loads (QUANTITY)

All waste generated by these sources was considered domestic, although urban waste reported in the UWWTD database includes a share of waste from commercial, industrial, and tourism activities. After allocating domestic waste spatially across Europe (Fig. 9), the associated emissions of Nitrogen N, Phosphorous P and BOD loads were estimated assuming them to be dependent on human diet following Bouraoui et al. (2009; 2011) and Morée et al. (2013). In the POP approach, shares of connected population (Pop_0 to Pop_3) or disconnected but treated in IAS (Pop_IAS) were transformed in PE loads using the PRE equivalence definition, i.e. adding a commercial, industrial and tourism component to that of resident population. Conversely, population in scattered dwellings (Pop_RES_SD and Pop_SD) were considered as produced solely by resident inhabitants (1 PE per inhabitant in this case).

Emissions of N and P from human excreta were estimated based on protein consume (Jönsson & Vinnerås, 2004), derived from 2009-2011 protein intake (FAO, 2016; Table 3). Consume was considered equal to intake less a 20% of retail losses for vegetable proteins and 11% for animal proteins, and a further 3% of losses through sweat/hair/blood (Morée et al., 2013). Therefore, N and P emissions per PE and per diem were calculated as:

$$N_{emissions} = (1-0.03)*0.11*(VEGPRT*(1-0.2)+ANIMPRT*(1-0.11)) \quad (1)$$

Table 3. National statistics of vegetable (VEGPRT) and animal (ANIMPRT) protein intake (g/day/PE) for 2009-2011 (FAO, 2016) and P in detergents in 2005 (kg/y/PE; Bouraoui et al., 2009).

Country	VEGPRT g/day/PE	ANIMPRT g/day/PE	P in detergents kg/y/PE
Albania	51	50	0.235
Austria	64	42	0.0948
Belarus	52	40	0.0897
Belgium	60	42	0.0821
Bosnia Her	31	59	0.451
Bulgaria	39	43	0.1162
Croatia	46	37	0.5271
Cyprus	48	31	0.5496
Czech Republic	54	38	0.2843
Denmark	67	40	0.1706
Estonia	52	44	0.1706
Finland	69	43	0.1327
France	72	41	0.3664
Georgia	26	49	0.1162
Germany	62	41	0.1074
Greece	63	49	0.3032
Hungary	45	37	0.2274
Iceland	96	36	0.1579
Ireland	62	46	0.0569
Italy	60	51	0.0632
Latvia	58	39	0.1958
Lithuania	75	49	0.1895
Luxembourg	69	43	0.0948
Macedonia, FYR	32	48	0.235
Malta	59	50	0.3791
Moldova	33	39	0.0459
Montenegro	58	53	0.235
Netherlands	73	35	0.0821
Norway	65	44	0.1137
Poland	52	49	0.5244
Portugal	70	44	0.4043
Romania	51	55	0.0897
Russian Fed.	54	47	0.0897
Serbia	37	44	0.235
Slovak Republic	36	38	0.1579
Slovenia	58	42	0.1074
Spain	66	39	0.3854
Sweden	71	37	0.1579
Switzerland	59	35	0.1137
Turkey	31	72	0.1162
Ukraine	41	45	0.0433
United Kingdom	58	44	0.3285

$$P_{emissions} = (1-0.03)*0.011*(2*VEGPRT*(1-0.2)+ANIMPRT*(1-0.11)) \quad (2)$$

where VEGPRT is the vegetable protein intake, and ANIMPRT is the animal protein intake (g/day/PE). An additional source of P emissions in domestic waste is due to use of detergents. P emissions for this source were estimated with Bouraoui et al. (2009; Table 3) with data of year 2005. Emission of BOD was assumed equal to 60 g/day per PE as per UWWTD database definition, although BOD emissions in Europe may vary from 40 to 70 g depending on diet (Powley et al., 2016).

In the REP approach, emissions were multiplied by PE entering WWTPs (PE_UWWTP). In the POP approach annual loads from connected population were reduced by 10%, accounting for losses occurring in sewerage system (Morée et al., 2013). Note that these 10% sewerage losses were not applied to PE_UWWTP, as PE loads entering WWTPs already accounted for them. Daily emissions were then transformed into annual loads ($Load_{in}$, t/y) undergoing treatment level.

2.2.3 Treatment pollution removal (ABATEMENT)

Annual loads of domestic waste emissions were computed as:

$$Load_{out} = Load_{in} (1-eff) \quad (3)$$

where $Load_{out}$ is the annual pollutant emission load (t/y of Nitrogen, Phosphorous, or BOD); $Load_{in}$ is the annual load undergoing treatment, and eff is the treatment removal efficiency. Removal efficiencies per treatment level were adopted from literature (Table 4; based on Nelson and Murray 2008; Fuhrmeister et al., 2015; Powley et al., 2016; Wen et al., 2017). BOD efficiencies were set after calibration of BOD fluxes in Europe (Vigiak et al., in preparation) within the range of literature values. Scattered dwellings (SD) were considered to be equipped with septic tanks; for SD a further 10% loss of N incoming load through volatilization was applied (Morée et al., 2013).

Table 4. Treatment removal efficiencies adopted in this study.

Treatment level	N	P	BOD
Septic Tank (Scattered Dwellings)	0.25	0.30	0.40
T1 - Primary	0.25	0.30	0.50
T2 - Secondary	0.55	0.60	0.94
T3 - Tertiary	0.80	0.60	0.96
T3P - Tertiary + P_removal	0.80	0.90	0.96

WWTP treatment types are reported in the UWWTD database, however only nutrient removal technologies were considered to assign tertiary treatment level. WWTP treatment levels for nutrient were thus assigned as follows: tertiary when Nitrogen or Phosphorus removal was indicated; secondary when secondary treatment was specified, primary in all other cases.

Noteworthy, in this way primary level was assigned to WWTPs which had no indication of treatment reported in the UWWTD database (1424 cases), and to 394 ambiguous cases.

Phosphorous removal technology improves tertiary treatment P efficiencies sensibly (T3P; Table 4). In the UWWTD database adoption of Phosphorous removal is specified. National statistics (POP approach) report this information partially (Eurostat, 2018b). However, the fraction of tertiary WWTPs that include P removal in the UWWD database is generally higher than Eurostats (2018b) data, possibly because the UWWTD database is more recent. Thus the rate of Phosphorous removal adoption in tertiary treatment (T3P/T3) as estimated from UWWTD database was applied to both the REP and POP approaches (Annex 1). In countries not covered by UWWTD database, for which no data was available, all tertiary treatment was considered without P removal technology (T3 only).

2.2.3.1 Checking of emission loads and removal efficiencies with UWWTD database data

For a minority of UWWTPs, the UWWTD database reports incoming and exiting loads of Nitrogen, Phosphorous and BOD. When the reported loads were consistent with incoming PE load (Table A3.7 in Annex 3), and treatment level was unambiguously declared, this information was used to (i) test whether the estimation of pollutant loads from domestic waste (Section 2.2.2) was correct, and (ii) compare reported treatment efficiencies with those assumed in this study (Table 4). However, the data was not retained in the final point source assessment to avoid methodological inconsistencies, especially when using the dataset for scenarios analysis.

In Figure 10, declared incoming loads (as reported in UWWTD database, reported $Load_{in}$) are compared with incoming loads estimated from domestic waste based on human diet (as described in Section 2.2.2). The 1:1 line indicates that the estimated incoming loads are in good agreement with those declared; linear regression coefficients were 1.08 for N ($AdjR^2$ = 0.90), 0.94 for P ($adjR^2$ = 0.87) and 0.83 for BOD ($AdjR^2$ = 0.74). Thus estimates of N emissions per PE in our study are slightly lower than declared values, whereas BOD are slightly higher.

A large variability can be observed in the reported efficiencies, with interquartile ranges being larger than 0.2 (Table 5). Mean efficiencies from declared data however compare very well with the ones assumed in this study (Table 4); assumed efficiency for BOD at secondary level and for P removal appear slightly higher than mean values from declared data sample but within the interquartile range. In any case, table 5 indicates that removal efficiencies are a source of uncertainty in the estimation of domestic waste emissions.

Figure 10. Comparison of pollutant incoming loads (N, P and BOD; t/y) reported in the UWWTD database (y axis) and the corresponding loads estimated based on human diet (Section 2.2.2, x axis). The dashed grey line indicates 1:1 relationship. Sample sizes are reported in Table 5.

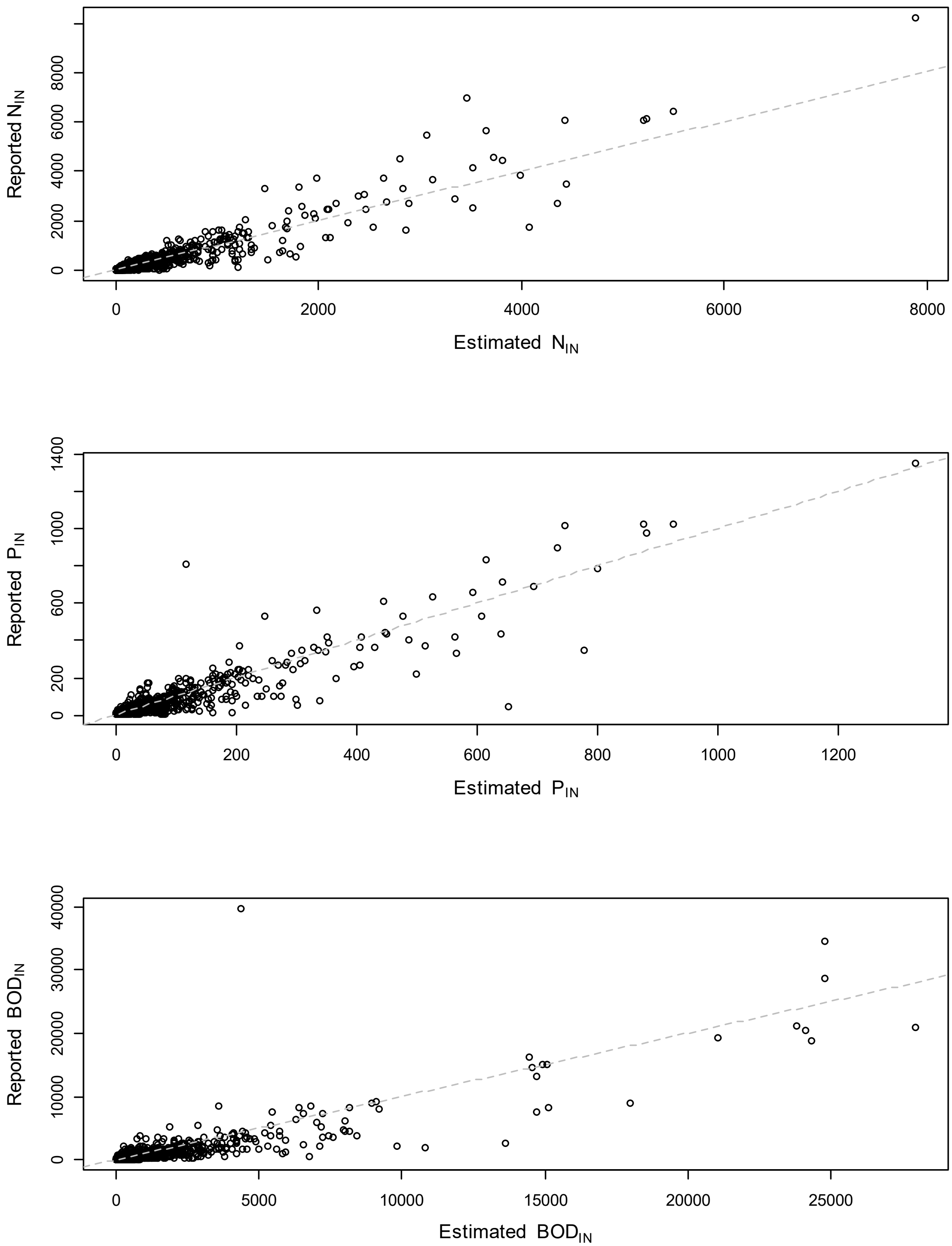


Table 5. Removal efficiencies for incoming and outgoing UWWTPs reported in the Waterbase-UWWTD database. IQR = Interquartile range, NA = Not applicable. UWWTP data was retained when the reported loads were consistent with incoming PE load and treatment level was unambiguously declared (Annex 3)

		N	P	BOD
number of WWTPs		6999	4314	2733
Primary	# WWTPs	11	5	33
	Mean Efficiency	0.36	0.36	0.50
	IQR efficiency	0.19-0.51	0.10-0.50	0.25-0.75
Secondary	# WWTPs	1214	570	841
	Mean Efficiency	0.50	0.59	0.90
	IQR efficiency	0.39-0.71	0.50-0.71	0.68-0.95
Tertiary	# WWTPs	5774	596	1859
	Mean Efficiency	0.77	0.61	0.97
	IQR efficiency	0.70-0.90	0.50-0.75	0.94-0.99
Tertiary + Phosphorous removal	# WWTPs	NA	3143	NA
	Mean Efficiency		0.82	
	IQR efficiency		0.75-0.92	

2.3 Assessment of industrial waste emissions to water

Emissions from industries connected to sewerage systems were already considered in the estimation of domestic waste, and amounting together with commercial and tourism activities to about 23% of generated waste.

In addition, the European Pollutant Release and Transfer Register database (E-PRTR; EEA, 2018) reports industrial releases to land, air and water from EU Member States, Iceland, Liechtenstein, Norway, Serbia and Switzerland. In this study v13, reporting emissions for years 2007-2016, was used. The record size in the database increased through the database lifetime, with year 2016 reporting the largest number of facilities. Mean emissions for the 2010s were estimated as the 7-year (2010-2016) average of declared annual releases, net of transfers to waste management facilities. This allowed considering the highest number of facilities in the database and acknowledging inter-annual variability of emissions.

The database reports spatial coordinates of industrial facilities and emissions of Total Nitrogen (N), Total Phosphorous (P), and Total Organic Carbon (TOC) to water. BOD was estimated from TOC based on molecular equivalence (BOD = 1.85TOC). This is a simplification, as the relationship between the two measures depends on type of industrial waste (e.g. Dubber and Gray 2010; Christian et al., 2017). E-PRTR Industrial emissions (IND) were added to point sources of both REP and POP approach. Emission loads were allocated to the catchment of the facility coordinates.

2.3.1 WWTP emission loads reported in E-PRTR

The E-PRTR reports emissions from large WWTPs (i.e. those with incoming loads above 100,000 PE or whose emissions are above minimum thresholds). To avoid duplication in accounting for WWTP emissions, WWTP entries in the E-PRTR were excluded from IND.

The presence of WWTPs in the E-PRTR database however provides another source of information about pollutant emissions of domestic waste, albeit limited to a sample of very large facilities. An independent study (van Duijnhoven and van den Roovart, 2018) analysed WWTP-related information reported in the E-PRTR and estimated median emission factors for N, P and TOC per PE and per treatment level. Table 6 reports the median emission factors and compare them with values estimated in this study (Section 2.2).

N emissions estimated in this study are slightly higher than van Duijnhoven and van den Roovart (2018) or declared emissions in the UWWTD database, probably because of the low efficiency assumed for primary treatment (0.25, Table 4). Conversely, P emissions for primary and secondary treatment estimated in this study were higher than what reported in the E-PRTR or UWWTD database. van Duijnhoven and van den Roovart (2018) did not separate tertiary treatment with or without P removal. However, most of tertiary WWTPs include Phosphorous removal technology (80% of tertiary facilities, treating 90% of incoming waste load treated at tertiary level according to UWWTD database). van Duijnhoven and van den Roovart (2018) emission factors concur with this study estimates and UWWTD reported emissions for Phosphorous removal level T3P.

To transform BOD into TOC, this study assumed the molecular ratio of 1.85 for all industries, however only for wastewater treatment Dubber and Gray (2010) reported a ratio of 1.68 +/- 0.375, so this error was included to assess TOC from BOD. For primary treatment, TOC estimations of this study concur with median emissions from E-PRTR, but are higher than what estimated with data declared in the UWWTD database. Conversely, at secondary or tertiary treatment this study estimates concur with UWWTD database but are lower than van Duijnhoven and van den Roovart (2018) estimates.

These data largely confirm the validity of assumptions taken in this study to assess emission loads and abatement, but highlight as well the uncertainty in the estimation of emissions.

Table 6. Comparison of emission factors of Total Nitrogen (N), Total Phosphorous (P) and Total Organic Carbon (TOC) per PE estimated by (i) van Duijnhoven and van den Roovart (2018) based on E-PRTR data; (ii) in this study; and (iii) in the UWWTD database subset of data.

		E-PRTR database (van Duijnhoven and van den Roovart, 2018)		Estimated in this study	UWWTD database	
		Median emission factor	Sample size	(Section 2.2)	Emission factor	Sample size
		kg/PE/y	#	kg/PE/y	kg/PE/y	#
N	T1	2.41	19	2.61	1.73	11
	T2	1.85	432	1.56	1.38	1214
	T3	0.83	812	0.70	0.78	5774
P	T1	0.2	21	0.53	0.18	5
	T2	0.17	416	0.31	0.15	570
	T3	0.08	714	0.30	0.16	596
	T3P			0.07	0.06	3143
TOC	T1	5.75	10	5.92 (5.33-8.40) *	3.17 (2.85-4.49) *	33
	T2	1.16	397	0.71 (0.64-1.01) *	0.89 (0.80-1.27) *	841
	T3	0.88	805	0.47 (0.43-0.67) *	0.47 (0.40-0.63) *	1859

* TOC was estimated from BOD assuming a ratio BOD/TOC = 1.85; Dubber and Gray indicated an interval of ratio 1.68 +/- 0.375. Values in brackets report TOC emission ranges when adopting this error.

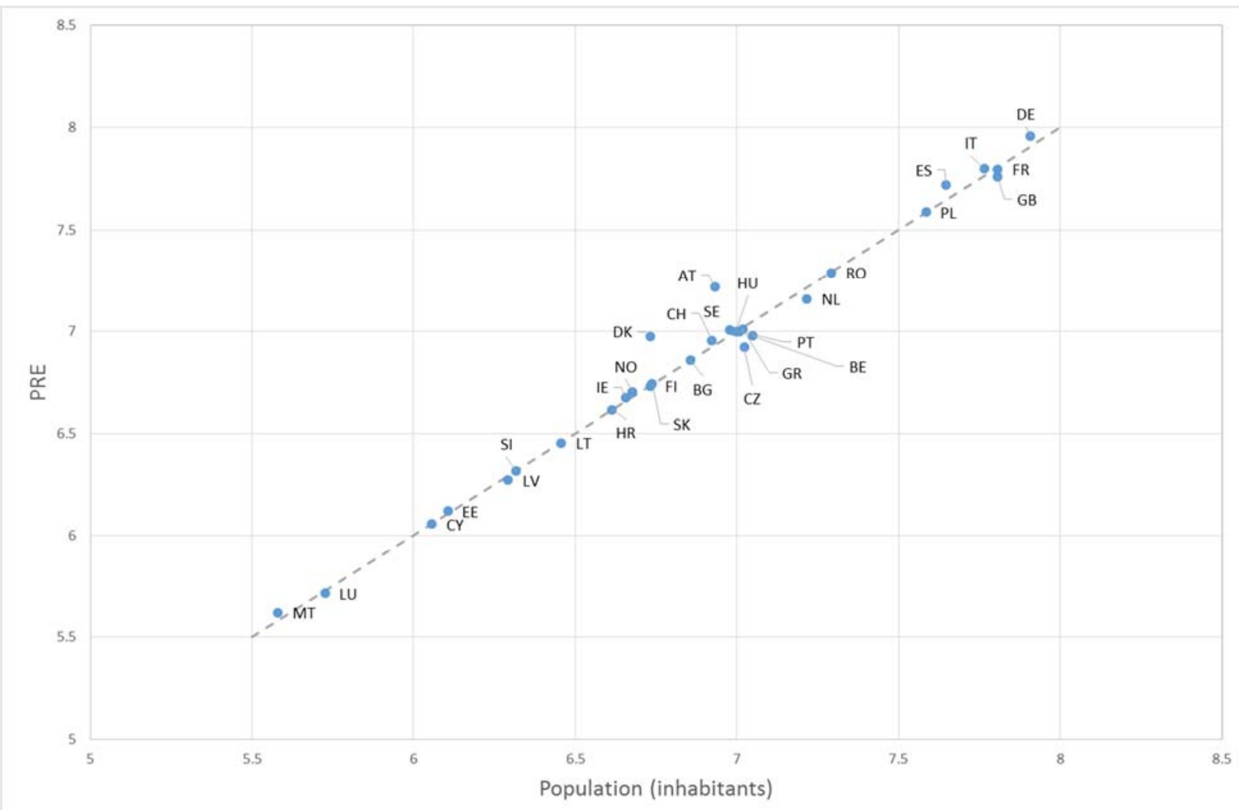
3 Results

3.1 Comparison of population shares by the REP and POP approach

Domestic waste emissions are a function of Population Resident Equivalent (PRE, estimated from PE in REP approach or inhabitants in POP approach). Thus, it is insightful to compare PRE, total and shares per treatment, under the REP and POP approaches.

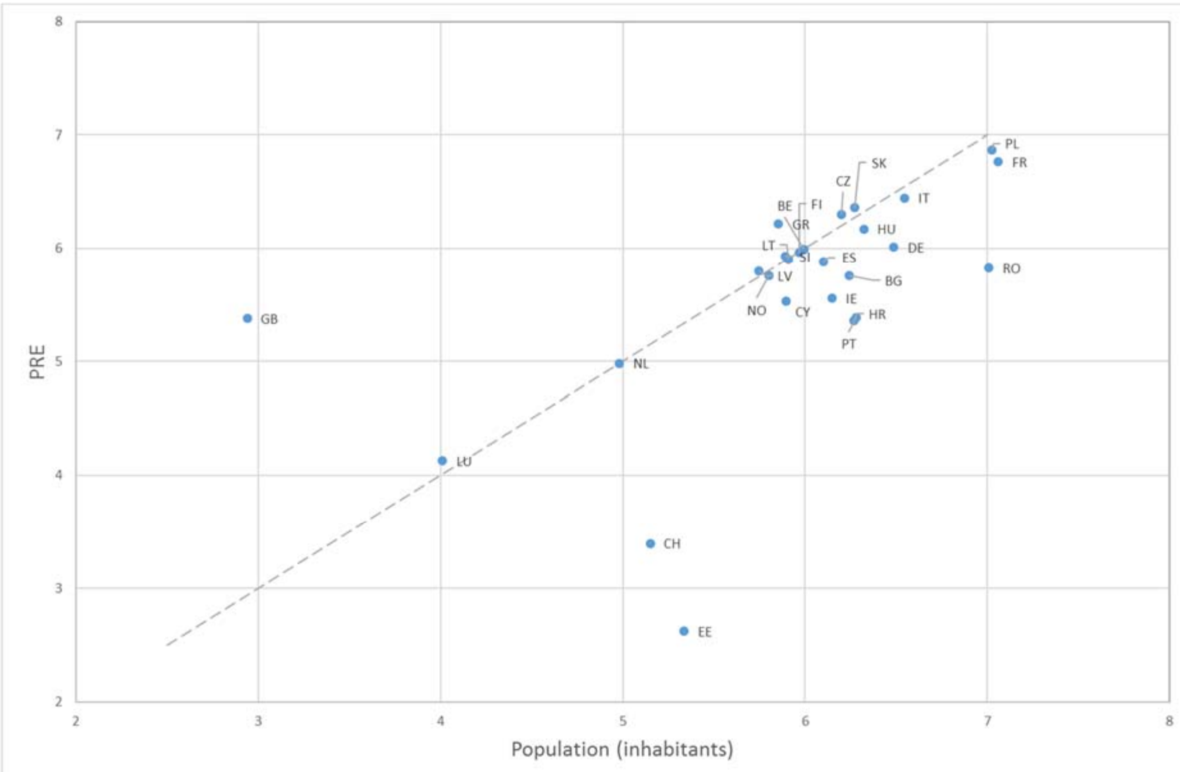
In terms of total population, the two approaches showed very good agreement, with a Pearson's correlation coefficient ρ of 0.99 (Fig. 11). This was achieved thanks to the introduction of 'residual population' to account for small dwellings that may be unreported in the UWWD database. Yet, in some countries, notably AT and DK, which reported large PE loads, PRE in the REP approach remains higher than residential population and above the 1:1 line. Conversely, others countries, like BE and CZ, reporting lower than expected PEs but small shares of disconnected or untreated population, lay below the 1:1 line. In these countries, differences in estimated PRE will be reflected in the emissions of domestic waste through the REP or POP approach.

Figure 11. Comparison of Population Resident Equivalent (PRE; inhabitants) estimated in the REP approach against total population (inhabitants) as derived from GHS2015. Dashed line indicates 1:1 relationship. Data are shown as log10 of PRE/inhabitants.



Larger differences among the two approaches emerge however when looking at shares of population by treatment level. The correlation between PRE in disconnected population was 0.78 (Fig. 12). This attests inconsistencies in data sources used in the two approaches. For example, the GB share of disconnected population in REP approach is much higher than in POP, because GB reports almost 300,000 PE treated via IAS (part of disconnected population, Table 2) whereas EUROSTAT reports all population as connected and treated (Table 1). Conversely, REP data indicates a lower share of disconnected population than in POP for CH, EE, RO.

Figure 12. Comparison of disconnected Population Resident Equivalent estimated in the REP approach (PRE) against population (inhabitants, Pop_DISC) as derived from the POP approach. Dashed line indicates 1:1 relationship. Data are shown as log10 of inhabitants.



At the same time CH, EE, RO report more population as connected not treated in the UWWTD database than through national statistics (Fig. 13). The case of IT represents the largest deviation between REP and POP approach for this share of population. In the UWWTD database IT reports 0.7% of connected not treated PE (Table 2), but national statistics indicate that about 30% of population as connected to sewerage but not treated (Table 1). Connected not treated population shares in the two approaches had no significant correlation and represent the most uncertain domestic source of pollution.

Correlation improved for primary treatment share (ρ = 0.79), albeit differences for some countries were large (Fig. 14). In this case, part of the discrepancies between the two approaches may have been generated by assuming primary treatment for WWTPS whose treatment type was not clearly reported in the UWWTD database. The assumption impacted the majority (> 75%) of WWTPs classified as primary treatment in BE, BG, CZ, ES, FI, HR, IE, LU, LV, RO, SI and SK. Conversely, it did not affect REP primary treatment for DE, GB or DK, which instead report larger shares of primary treatment through the UWWTD database than through national statistics (Table 2).

Figure 13. Comparison of connected not treated Population Resident Equivalent estimated in the REP approach (PRE_0) against population (inhabitants, Pop_0) as derived from the POP approach. Dashed line indicates 1:1 relationship. Data are shown as log10 of inhabitants.

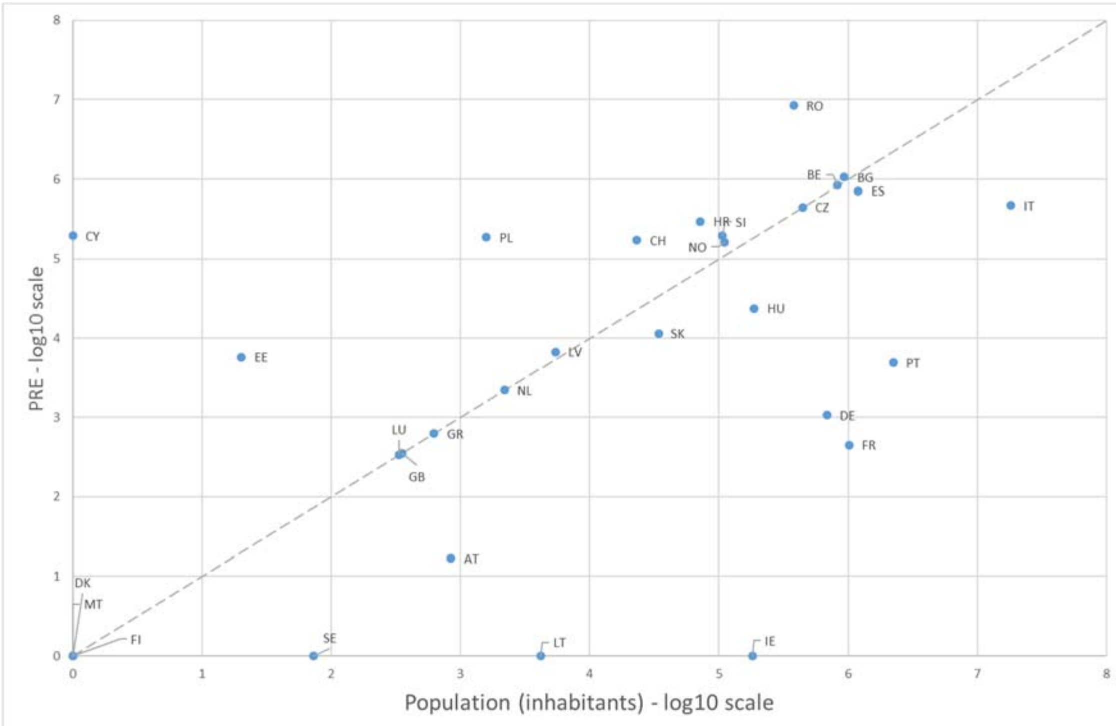


Figure 14. Comparison of Population Resident Equivalent estimated in the REP approach treated at primary level against population (inhabitants, Pop_1) as derived from the POP approach. Dashed line indicates 1:1 relationship. Data are shown as log10 of inhabitants.

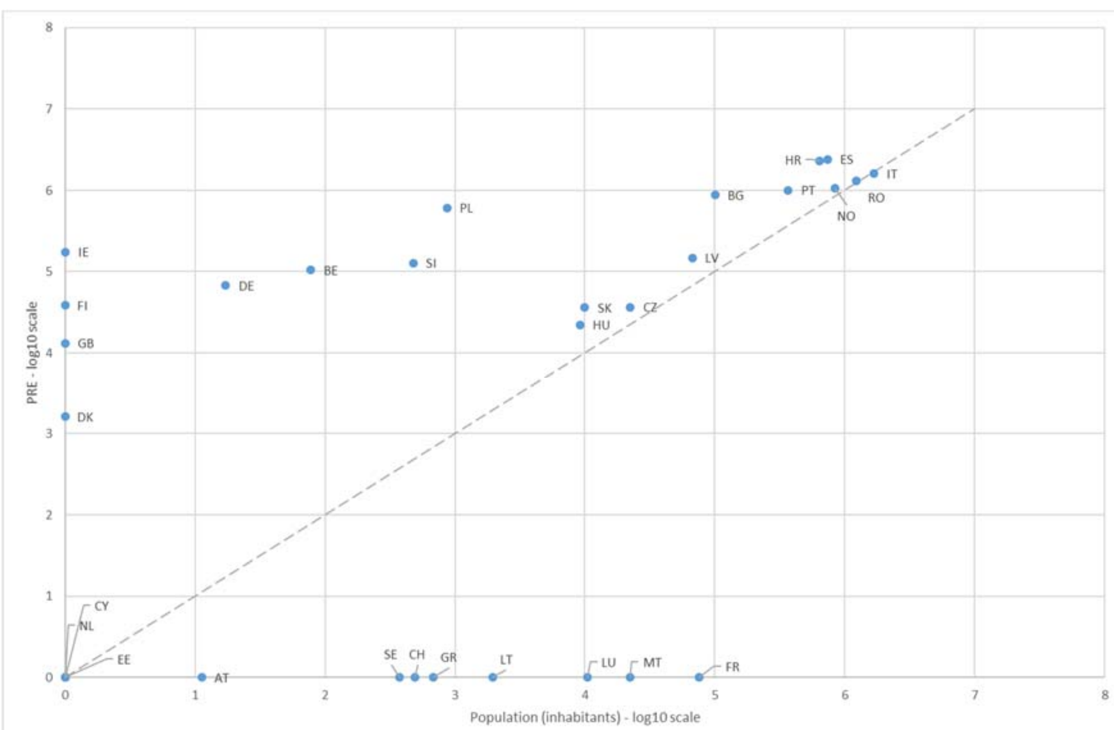


Figure 15. Comparison of Population Resident Equivalent estimated in the REP approach treated at secondary level against population (inhabitants, Pop_2) as derived from the POP approach. Dashed line indicates 1:1 relationship. Data are shown as log10 of inhabitants.

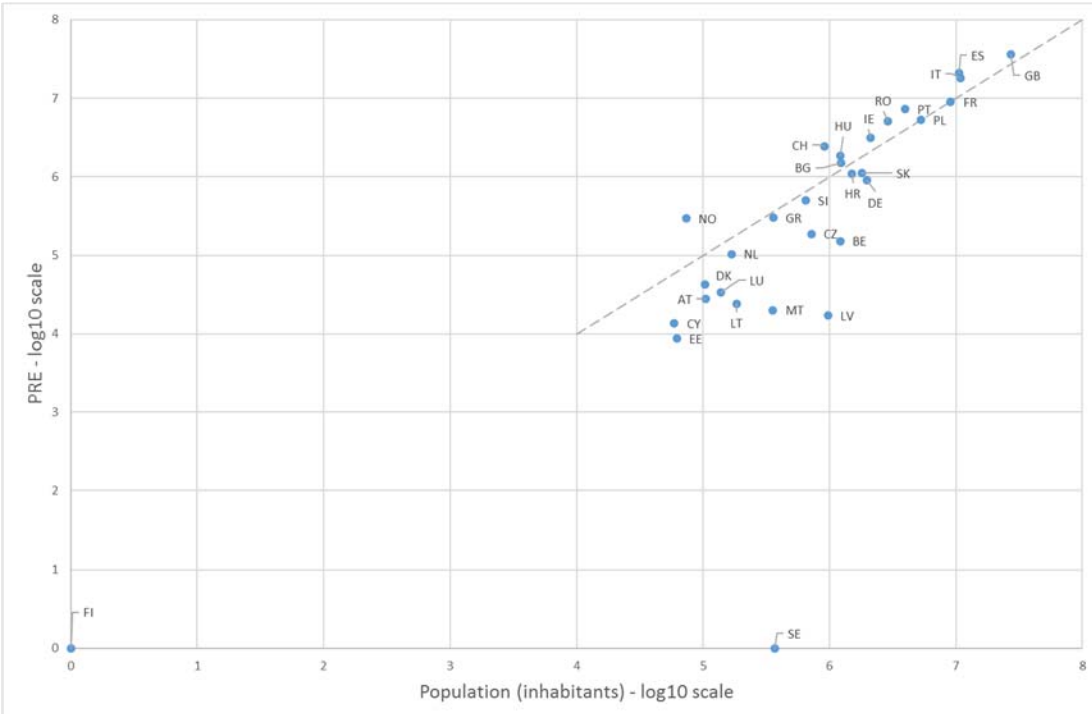
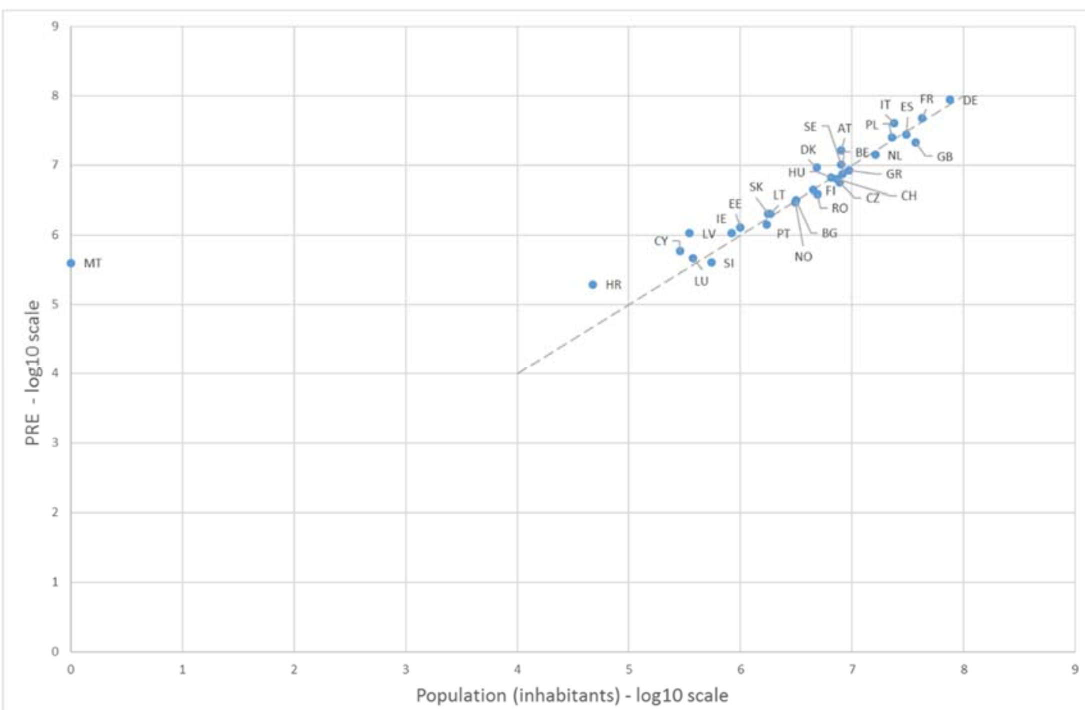


Figure 16. Comparison of Population Resident Equivalent estimated in the REP approach treated at tertiary level against population (inhabitants, Pop_3) as derived from the POP approach. Dashed line indicates 1:1 relationship. Data are shown as log10 of inhabitants.



The agreement between shares of population in secondary (ρ = 0.98) and tertiary treatment (ρ = 0.96) however increases substantially (Figs. 15 and 16). This is reassuring because shares of domestic loads treated at the secondary or higher level represent the large majority of population (89% of PE GEN).

Figures 12 to 16 highlight discrepancies in national reporting of domestic waste statistics through different channels. It is possible that interpretation of Eurostat statistics by reporting countries was different from the one assumed in this study (Table 1) and particularly that in national statistics shares of disconnected population were reported as connected not treated or vice versa. Differences in reporting periods and variability in the PE/Population rate further complicate comparisons. Yet, inevitably the attribution of population to treatment levels has important implications in the estimation of domestic waste emissions, as higher treatment implies larger pollution abatement while connected not treated emissions are the least abated source of domestic pollution.

3.2 Comparison of domestic waste pollutant emissions to water by REP and POP approach

Country emissions of Nitrogen, Phosphorous and organic matter (BOD) reflect the amount of population and the treatment abatement; differences between REP and POP approach arise from amount of population attributed at each treatment share.

3.2.1 Nitrogen emissions

Figures 17-19 show country annual emissions of Nitrogen by disconnected, connected and not treated, or connected to WWTPs population through the REP and POP approach.

Emissions from disconnected population were generally higher in the POP approach than in REP, except in CZ, GR, LT and SK (Fig. 17). According to the POP approach, the median contribution to N emissions by disconnected population is 34%; but this source of domestic waste generated more than 50% of domestic emissions in CY, HR, LT, PL, RO, SI, and SK. According to REP approach, disconnected population contributed in median to 11% of N emissions by domestic waste, but accounted for more than 50% of N emissions in LT, LV and SK. In absolute terms, FR and PL resulted in the largest emissions of Nitrogen by disconnected population in both approaches, followed by IT. Estimates for the two approaches were very different in RO and DE, with large proportions of disconnected population emissions estimated in POP approach.

The median N emission share by connected not treated population (T0, Fig. 18) was 1.3% for POP approach and 0.5% for REP approach. A very high contribution was estimated for IT under POP approach since about 30% of population was estimated to belong to this share (Table 1), and RO under the REP approach. Important contribution (>20%) to N emissions by this share of population was estimated for BE, BG, PT (POP approach only), and CY (REP approach only). Finally, the largest N emissions were estimated by WWTPs discharges, especially under the REP approach (Fig. 19), with the largest emissions estimated for the most populated countries (GB, DE, IT, FR and ES).

Figure 17. Nitrogen annual emission (t/y) per country under the REP and POP approach through disconnected population (scattered dwellings and IAS).

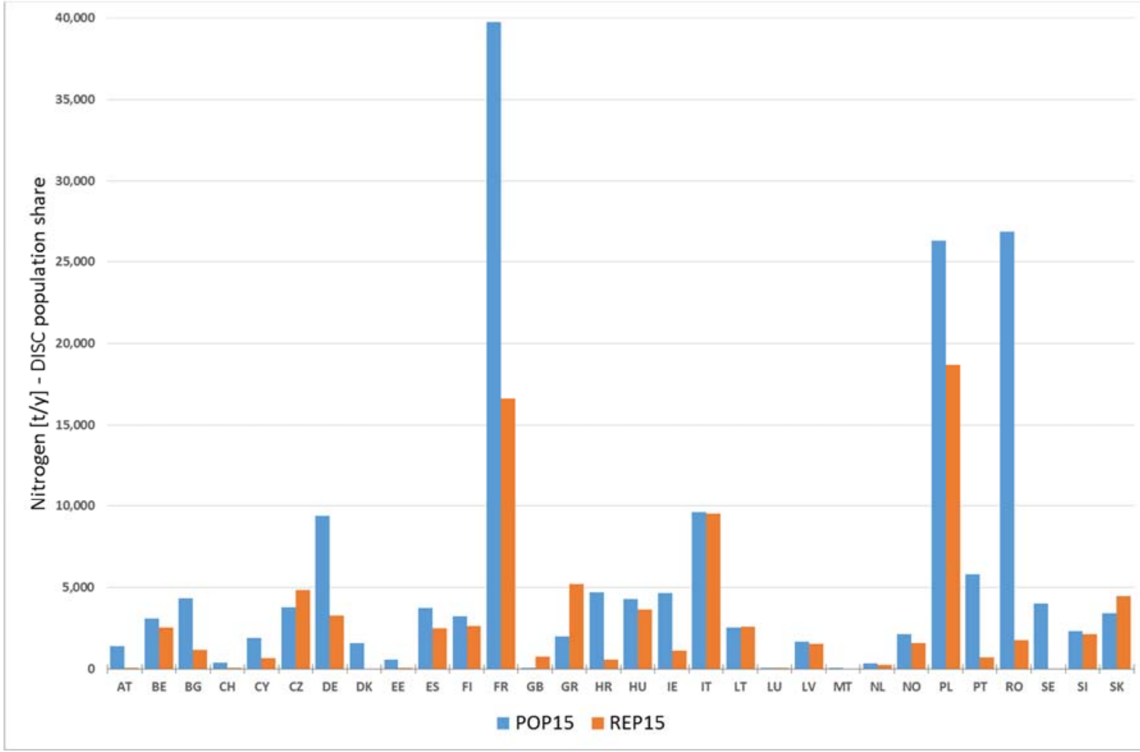


Figure 18. Nitrogen annual emission (t/y) per country under the REP and POP approach through connected not treated population (T0). Y-axis is cut at 35,000 t/y.

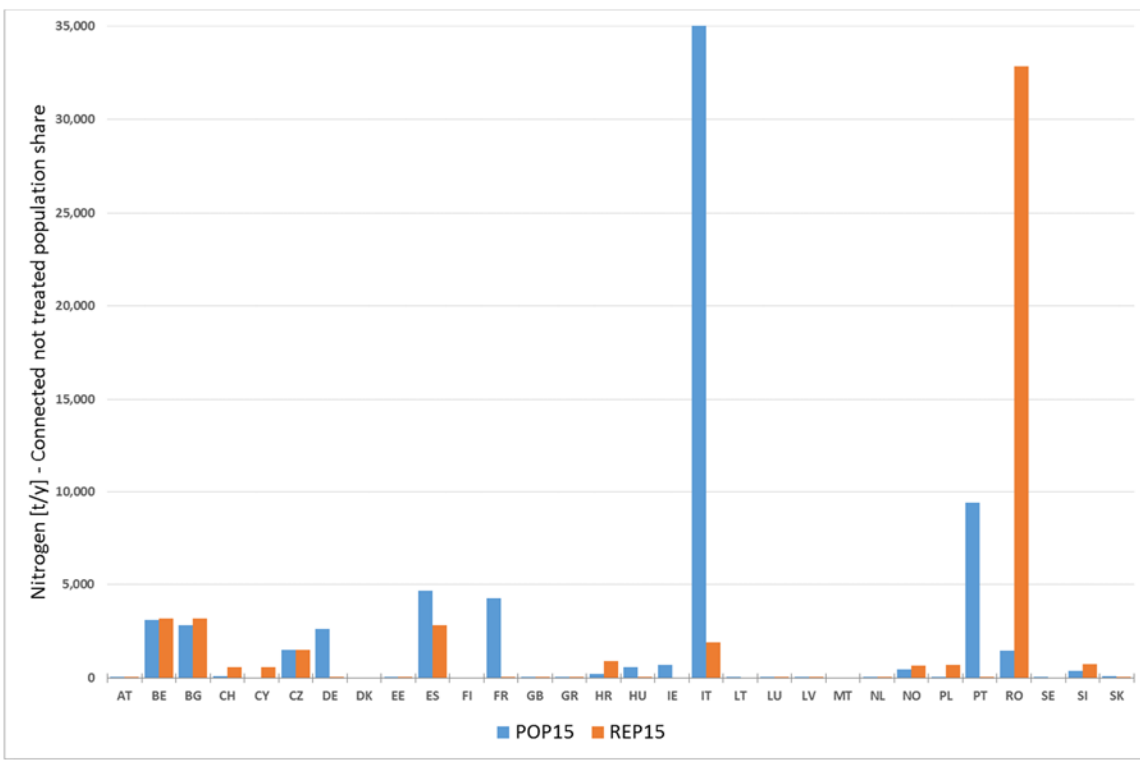


Figure 19. Nitrogen annual emission (t/y) per country under the REP and POP approach through connected and treated population (T1-T3).

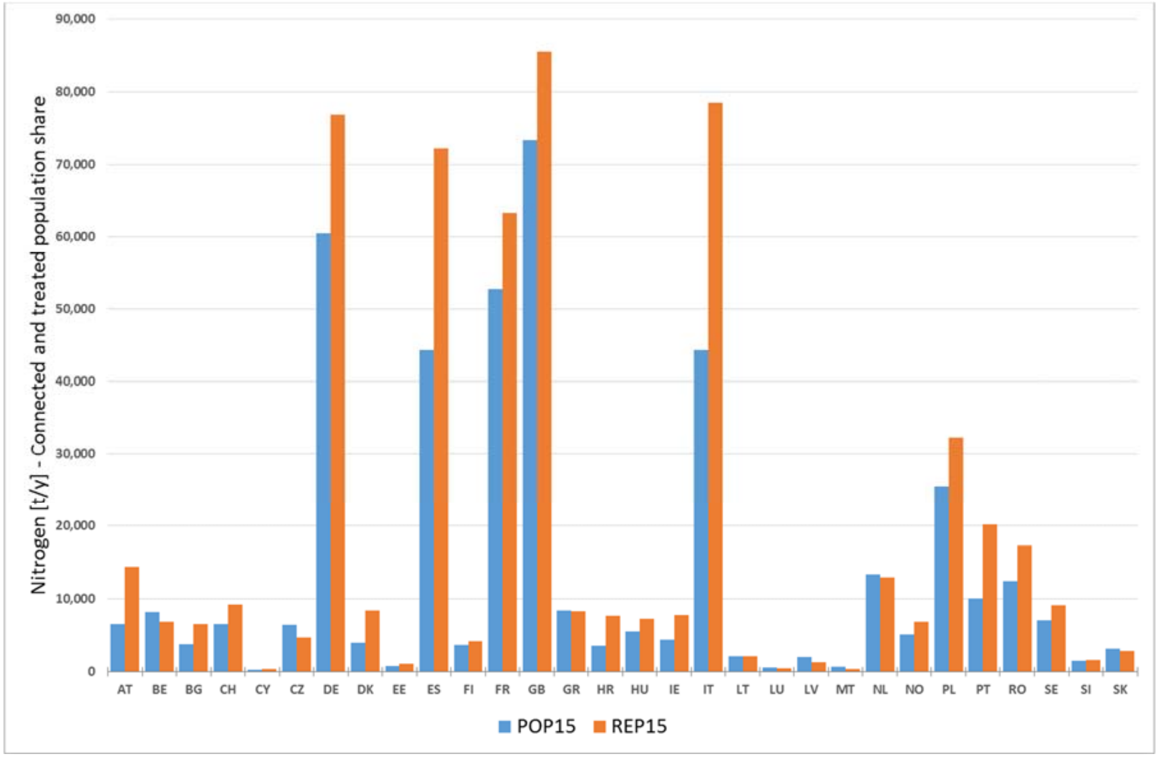


Figure 20. Total domestic waste Nitrogen annual emission (t/y) per country under the REP and POP approach.

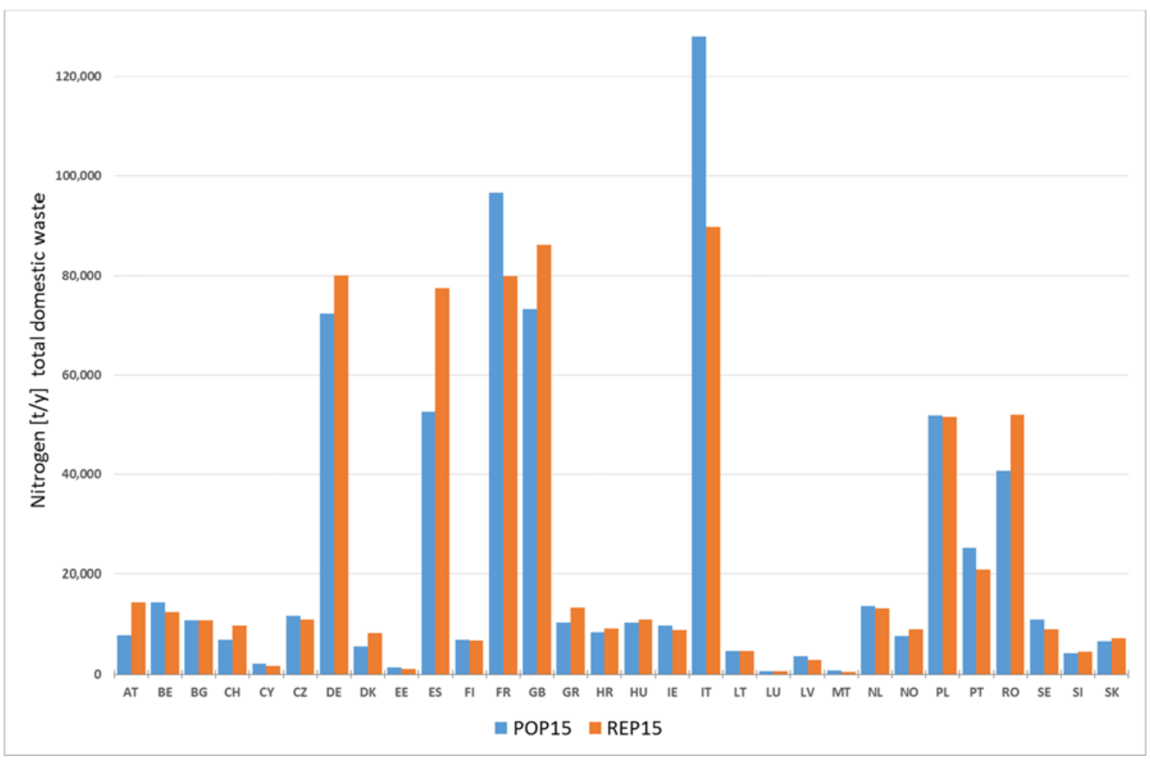
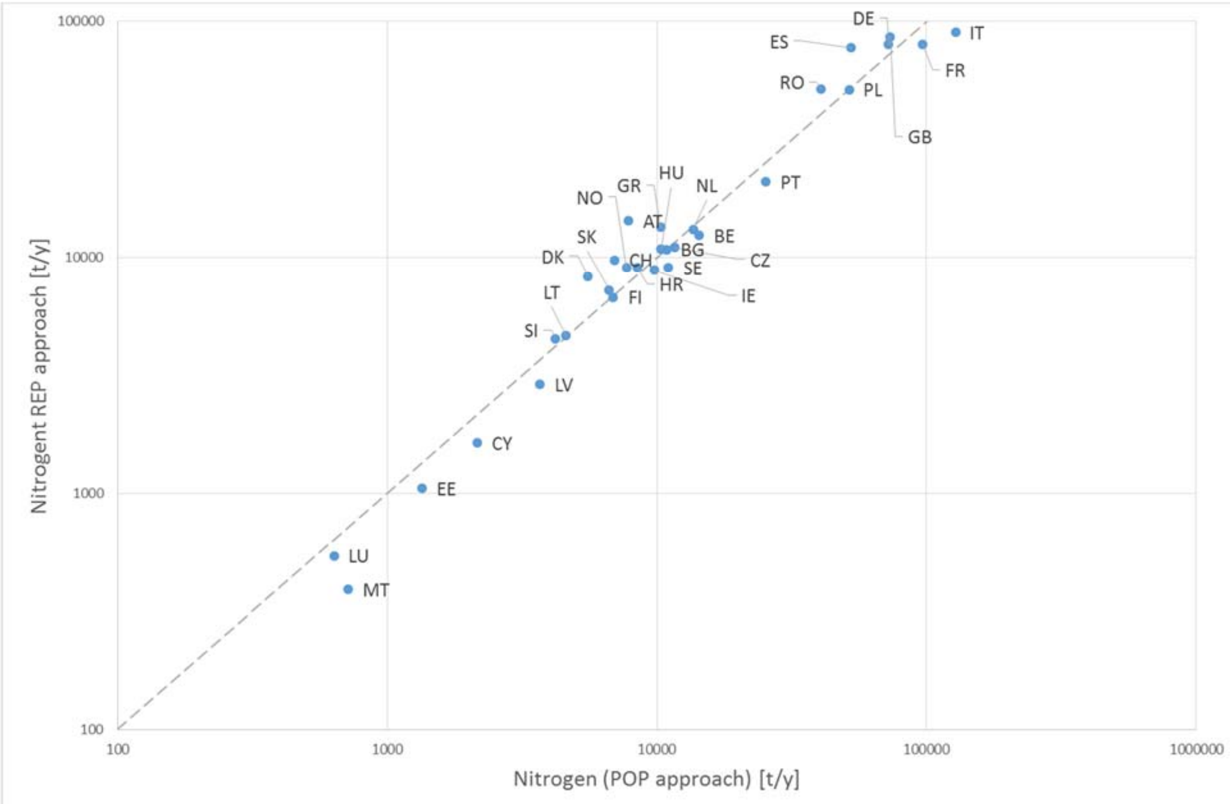


Figure 21. Comparison of total domestic waste Nitrogen annual emission (t/y) per country under the REP and POP approach (log10 scale). Dashed grey line indicates 1:1 relationship.



In total, N annual emissions for the 30 countries were estimated at slightly more than 700,000 t/y under both approaches, with large emissions (>70,000 t/y) estimated for IT, DE, GB, and FR in both approaches (Fig. 20). Differences between the two approaches can be visualized in Fig. 21, which present the scatter plot of the total N emissions by domestic waste under the two approaches (in log10 scale). Notwithstanding the differences among shares of population and total emissions, the two approaches are largely in agreement (ρ = 0.95).

3.2.2 Phosphorous emissions

Patterns of P emissions (Figs. 22-25) were very similar to those observed for Nitrogen. Under the POP approach emissions from disconnected population were generally larger, contributing 29% of emissions from domestic load across Europe, than for REP (Fig. 22), contributing to 16% of Phosphorous emissions. Similarly, contribution from connected not treated population under POP approach amounted to 16% of total, more than half of which generated in IT, whereas this percentage was 8% in the REP approach (Fig. 23). Phosphorous emissions from connected and treated population accounted for 55% of emissions in POP approach and 77% in REP (Fig. 24).

In total, Phosphorous emissions were estimated at slightly more than 120,000 t/y in both approaches (Fig. 25), with greater contributions from GB, IT, FR, ES and PL. Despite differences in the two approaches, there was a high correlation coefficient for total Phosphorous emissions (ρ = 0.94, Fig. 25).

Figure 22. Phosphorous annual emission (t/y) per country under the REP and POP approach through disconnected population (scattered dwellings and IAS).

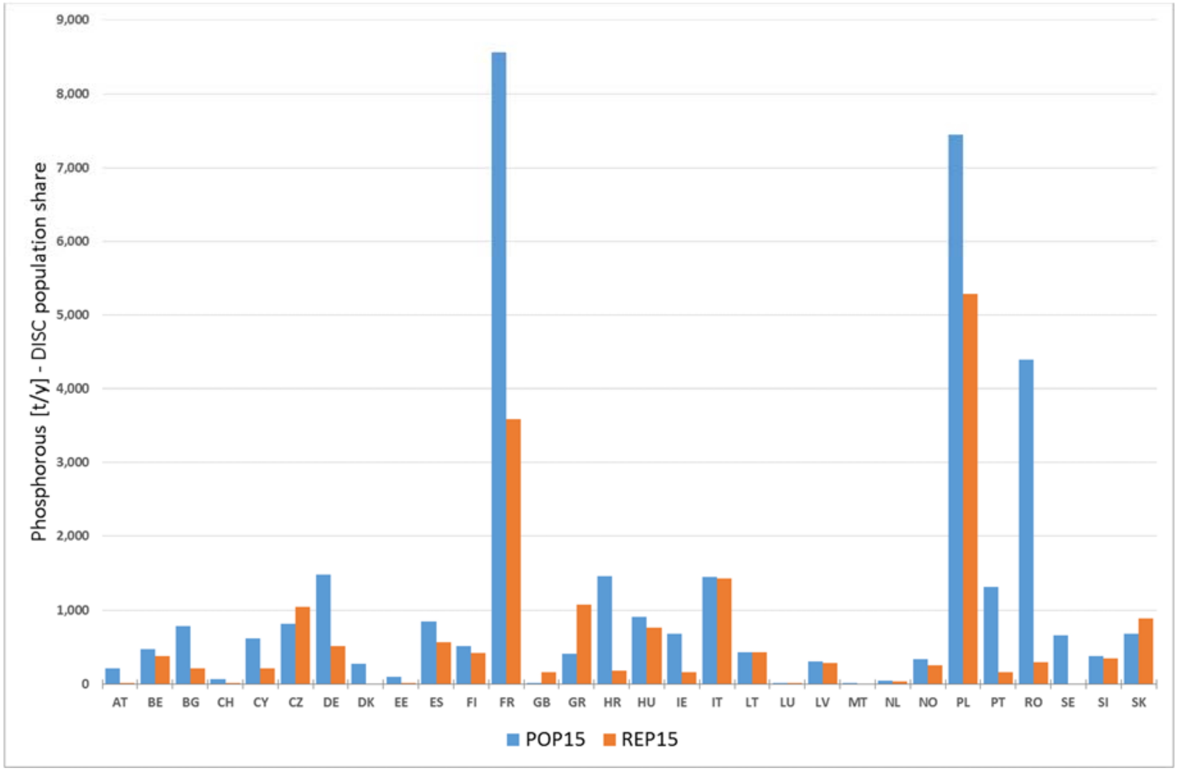


Figure 23. Phosphorous annual emission (t/y) per country under the REP and POP approach through connected not treated population (T0). Y-axis is cut at 6,000 t/y.

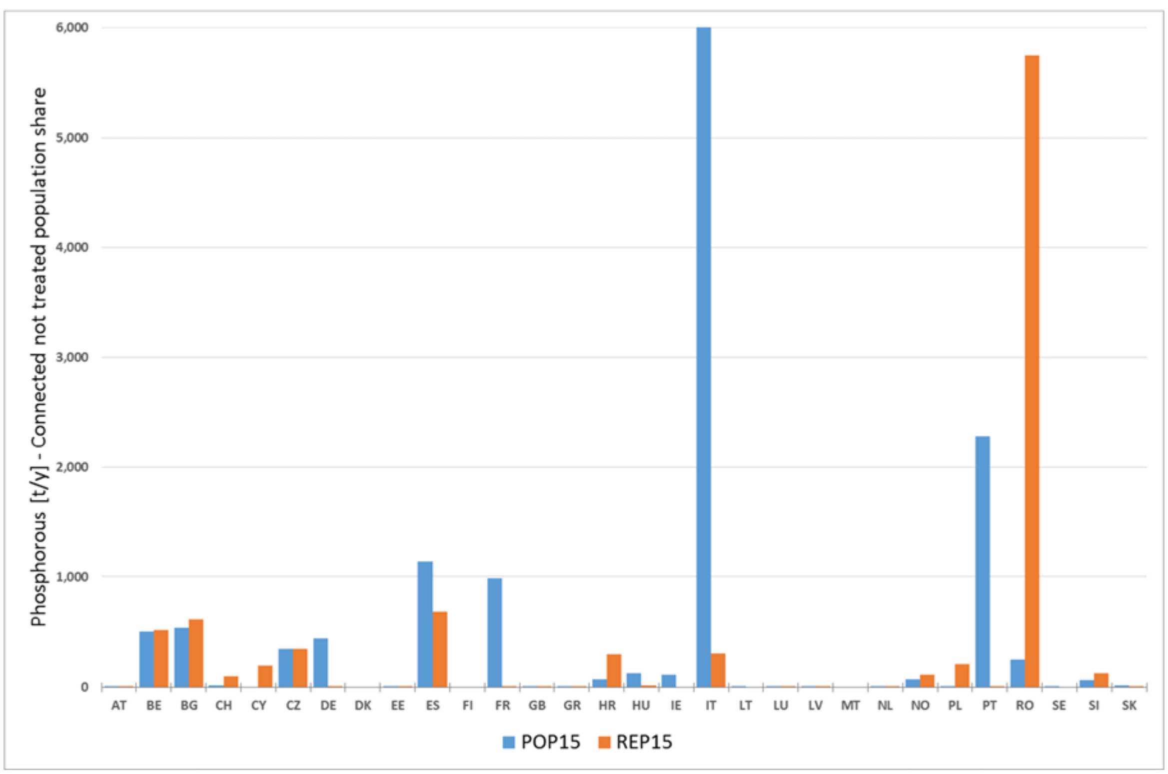


Figure 24. Phosphorous annual emission (t/y) per country under the REP and POP approach through connected and treated population (T1-T3).

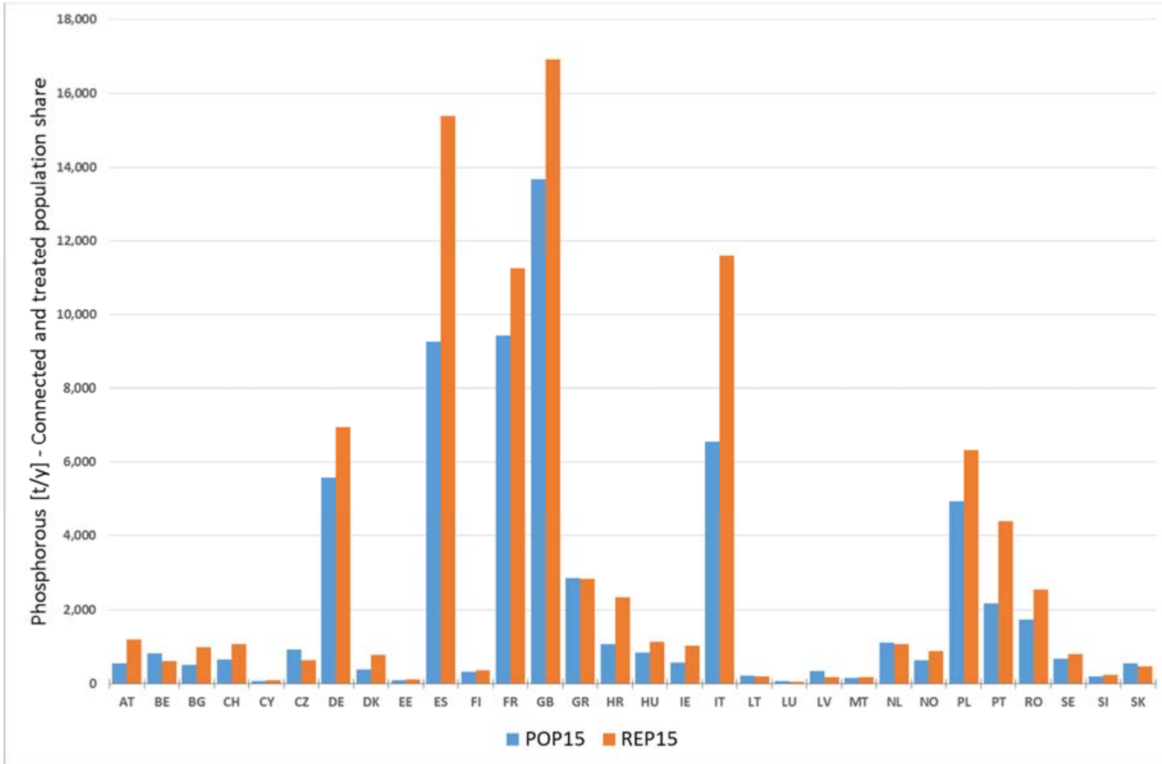


Figure 25. Total domestic waste Phosphorous annual emission (t/y) per country under the REP and POP approach.

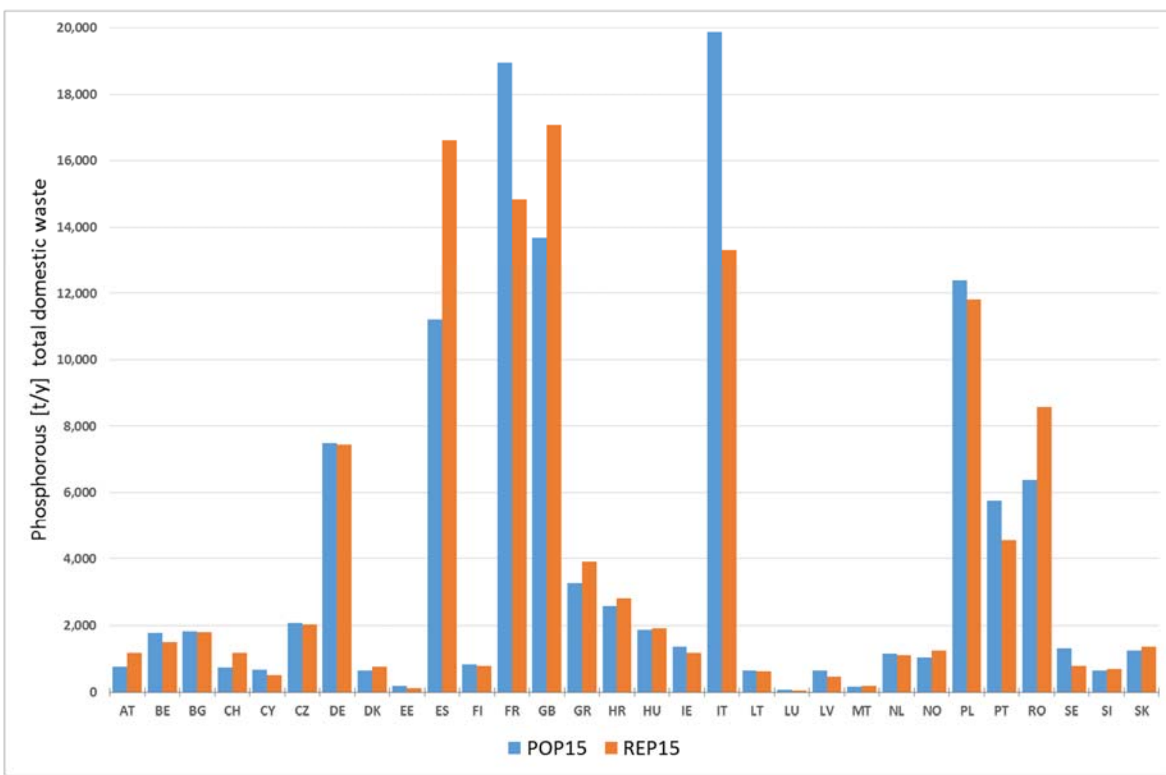
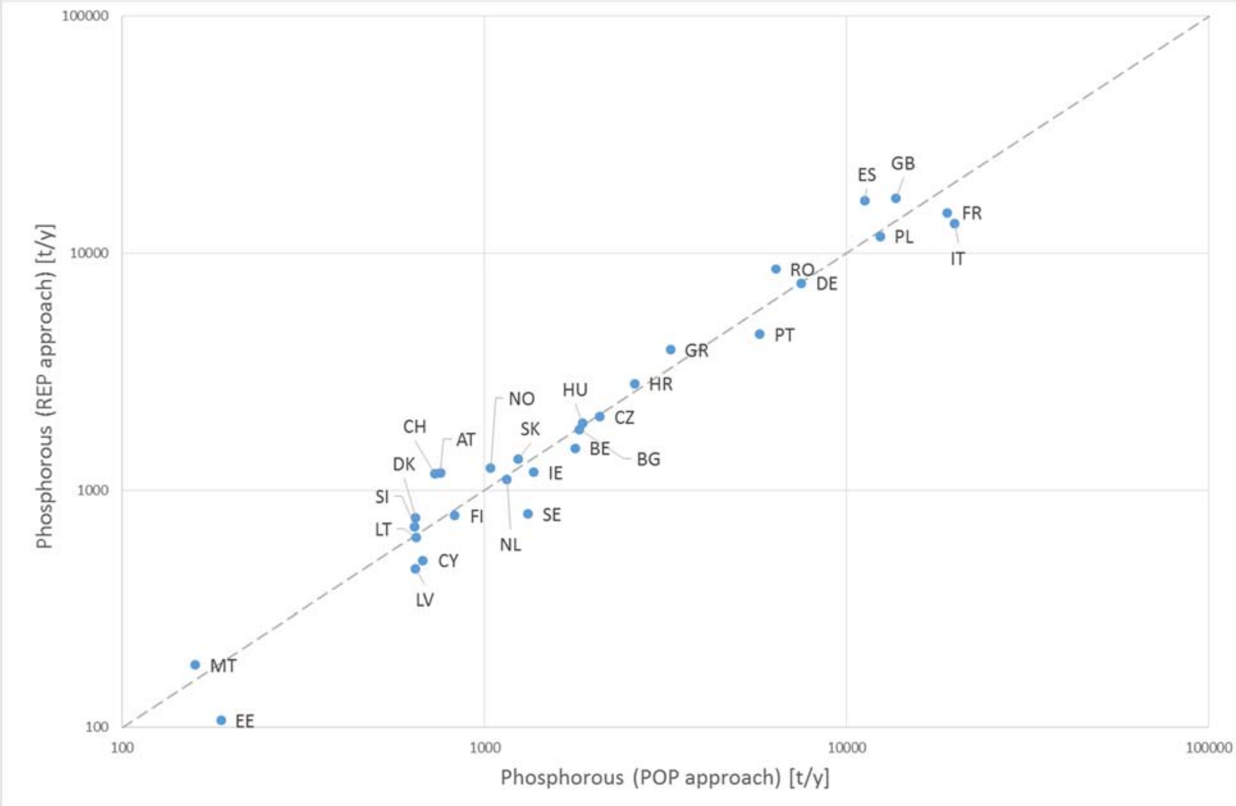


Figure 26. Comparison of total domestic waste Phosphorous annual emission (t/y) per country under the REP and POP approach (log10 scale). Dashed grey line indicates 1:1 relationship.



3.2.3 Organic matter (BOD) emissions

Patterns of BOD emissions differed from those of Nitrogen or Phosphorous especially because of the larger abatement of BOD in septic tanks or primary treatment compared to no treatment, and of secondary or higher level compared to primary treatment only, than for nutrients (table 4). Thus, the relative importance of connected not treated population or disconnected population was higher for BOD emissions than for nutrients. Contributions from disconnected population amounted to 41% of BOD emissions in POP approach and 29% of REP approach (Fig. 27). Contribution from connected not treated population under POP approach raised to 33% of total, more than half of which generated in IT, whereas this percentage was 22% in the REP approach (Fig. 28). Conversely, because of the very high efficiencies of BOD removal in secondary or tertiary WWTPs (Table 4), BOD emissions from connected and treated population was estimated at 26% (POP approach) or 49% (REP approach).

In total, BOD emissions were estimated at almost 1.5 M t/y in the REP approach, but were higher in the POP approach because of the high emissions from connected not treated IT population (Fig. 30 and 31). The major BOD contributors were the countries where T0 shares are very high (IT in POP approach and RO in REP approach), followed by those with important contributions from disconnected population, like FR and PL.

Figure 27. BOD annual emission (t/y) per country under the REP and POP approach through disconnected population (scattered dwellings and IAS).

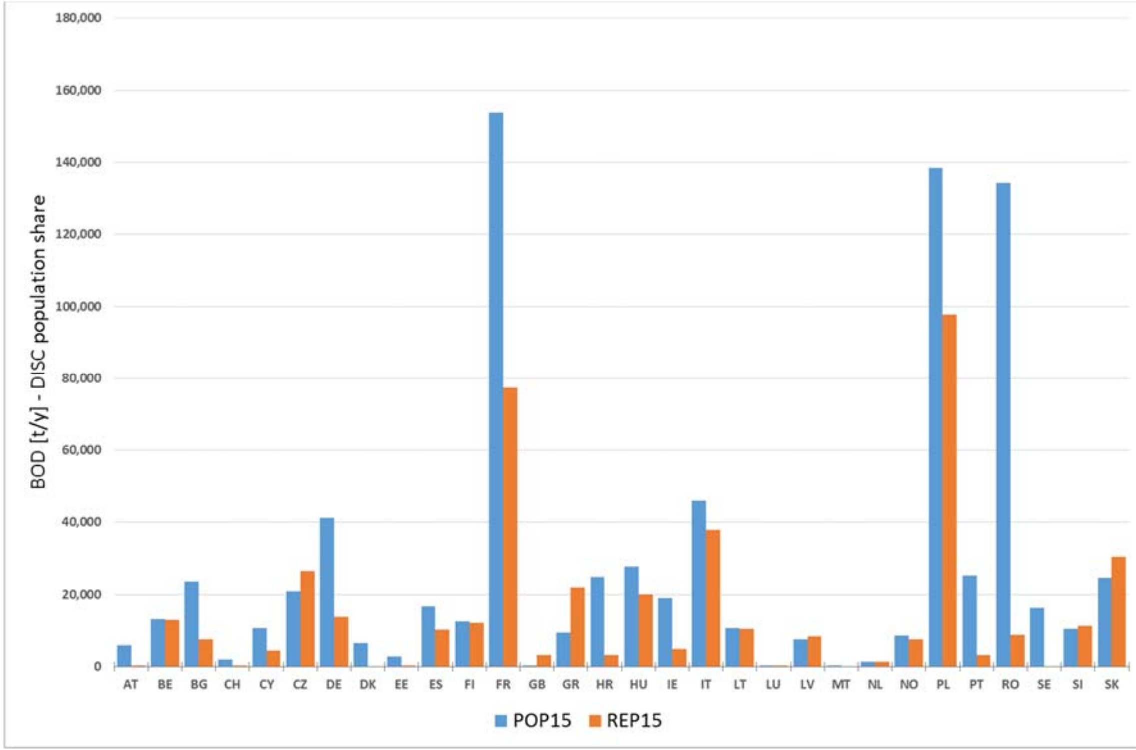


Figure 28. BOD annual emission (t/y) per country under the REP and POP approach through connected not treated population (T0). Y-axis is cut at 250,000 t/y.

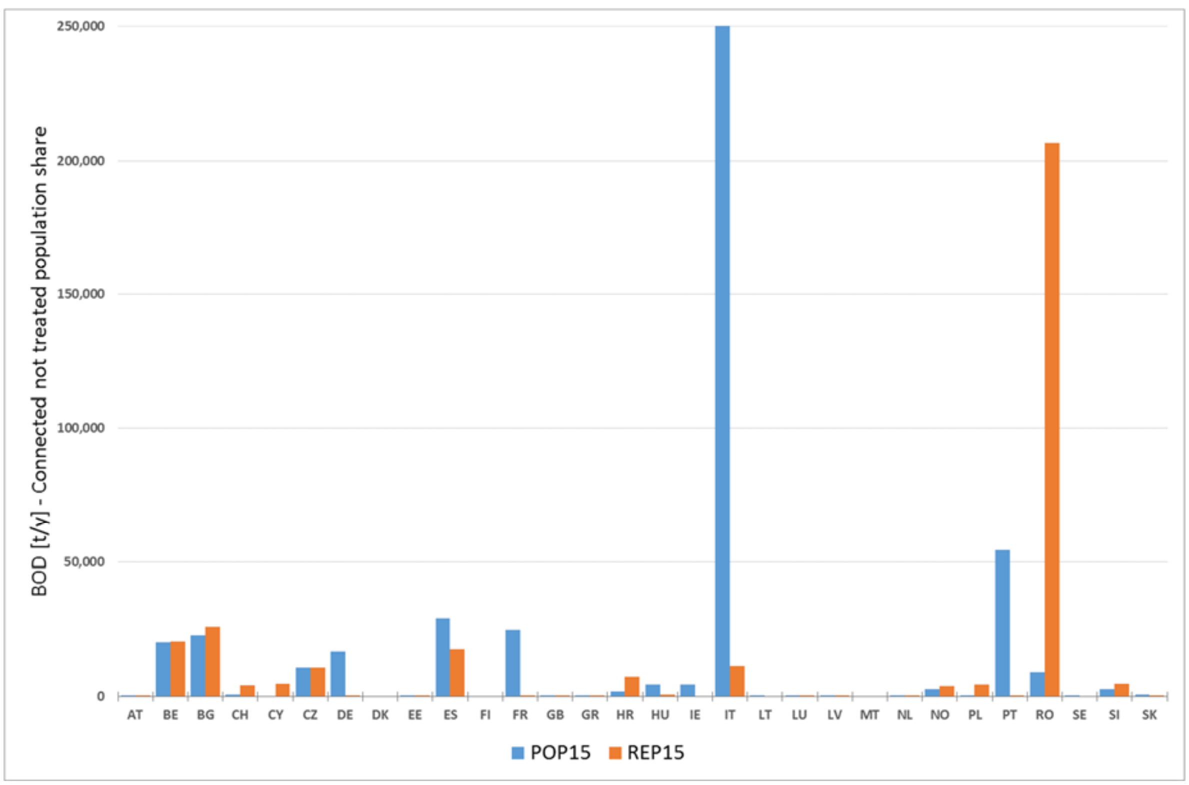


Figure 29. BOD annual emission (t/y) per country under the REP and POP approach through connected and treated population (T1-T3).

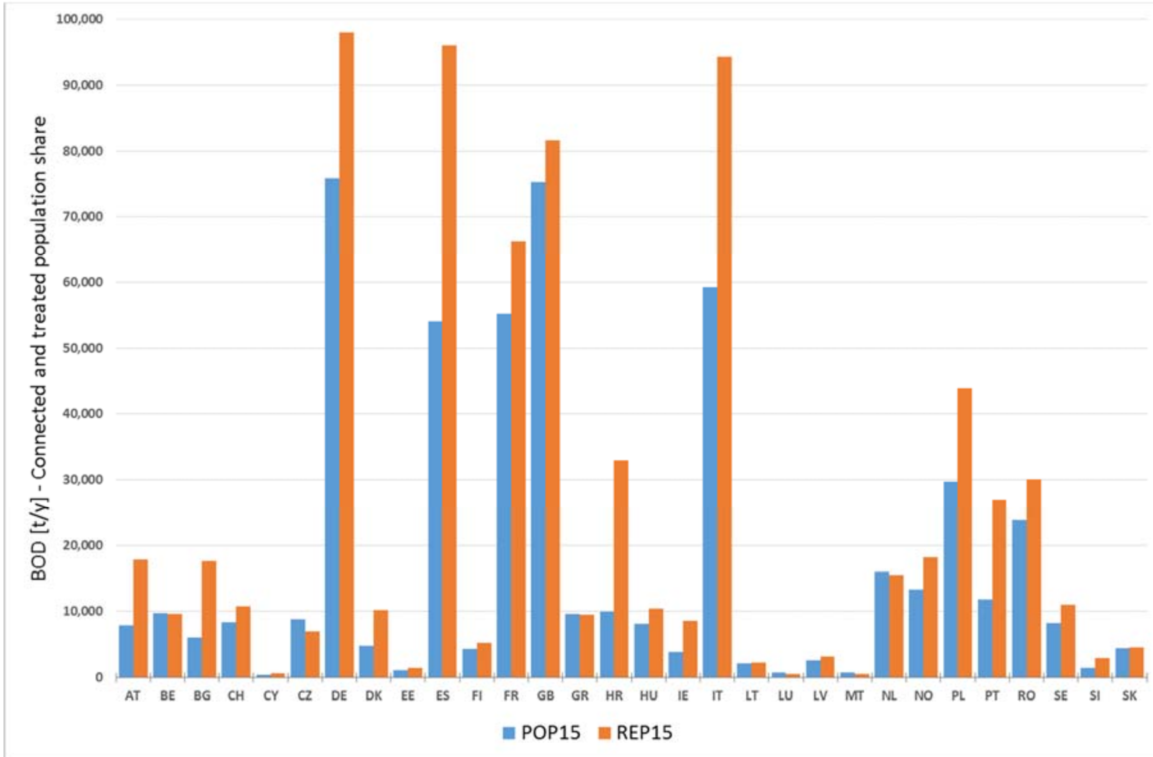


Figure 30. Total BOD annual emission (t/y) from domestic waste per country under the REP and POP approach. Y axis cut at 250,000 t/y

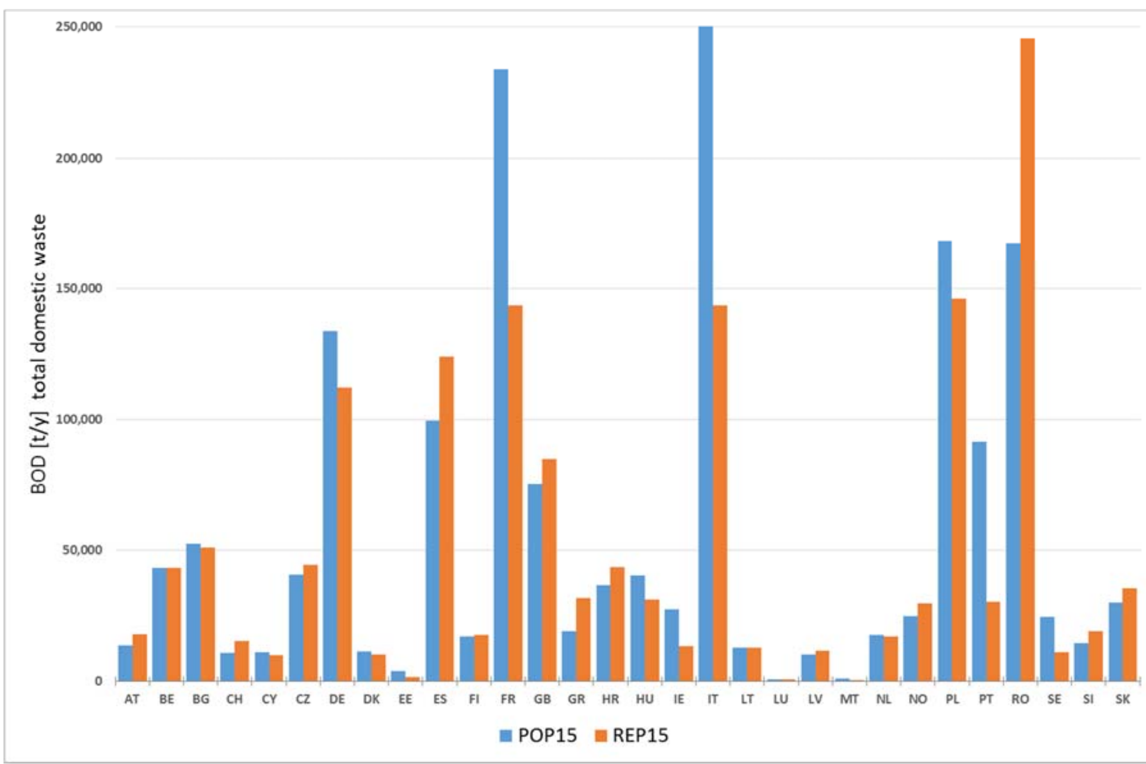
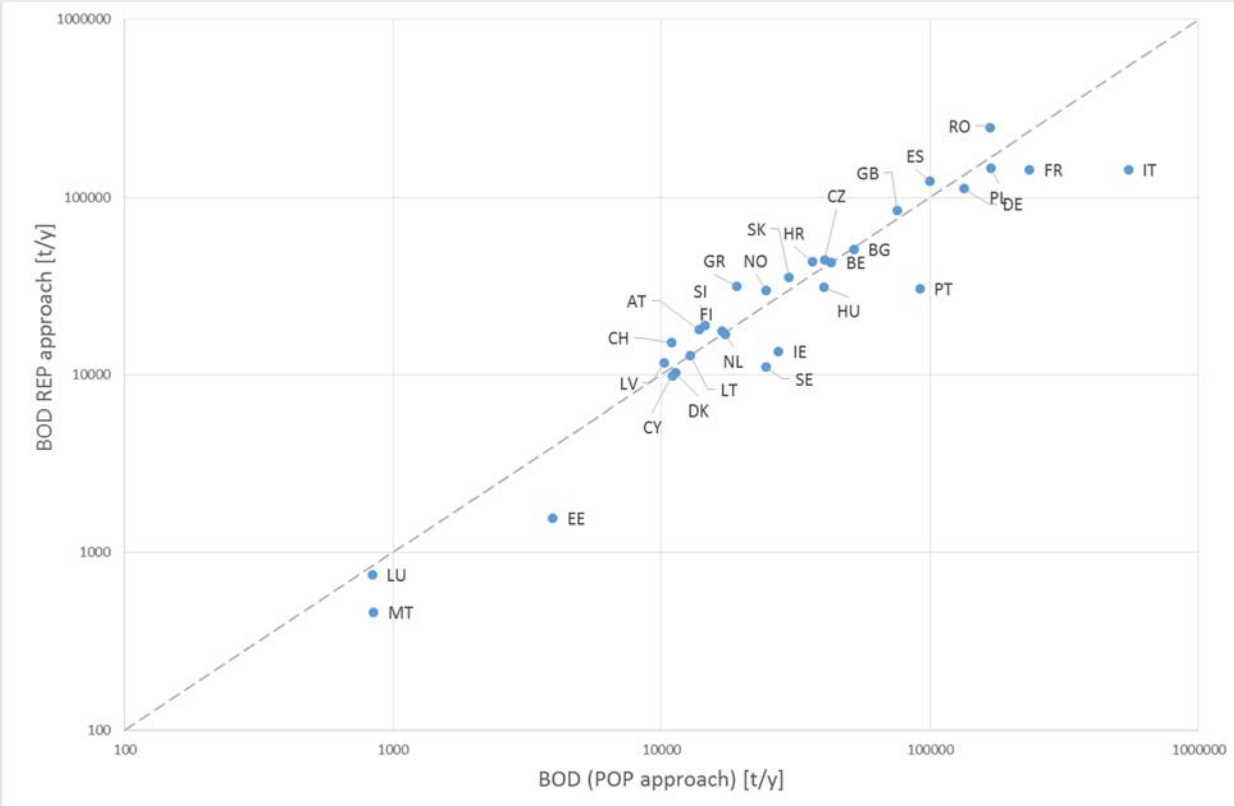


Figure 31. Comparison of total BOD annual emission (t/y) from domestic waste per country under the REP and POP approach (log10 scale). Dashed grey line indicates 1:1 relationship.



The high relative contribution of disconnected and connected not treated population in the BOD emissions combined with discrepancies in T0 population between the two approaches (Fig. 13) reduced the overall agreement in BOD emission estimations by the POP and REP approach (Fig. 31), lowering the correlation coefficient ρ to 0.71. When excluding IT from the sample, correlation coefficient ρ raised to 0.89.

3.2.4 Outcome of the comparison

Results of this section highlight how uncertainties in assessing population shares under different approaches propagate to emissions, and how these are impacted by abatement rates per treatment type. Two main conclusions can be drawn:

— 1) The good agreement reached in total domestic emission estimates by the two approaches prove that POP approach remains a valid alternative for areas and periods not covered in the UWWTD database. While this is true for total emissions, it does not hold for shares of emissions per treatment, so care should be taken in comparing results of population shares;

— 2) Both approaches suffer limits and uncertainties, raising on one side from the assumptions that had to be taken, and on the other side from the errors and inconsistencies that were detected in data sources of both approaches. Yet, the REP approach represents an important step forward in tracking domestic waste generation and fate, and is adopted in the remaining of this study as the reference approach for estimating emission sources in Europe in the 2010s.

3.3 Domestic emissions to water in the 2010s.

Mean annual domestic waste across Europe was therefore assessed with the REP approach, but integrating estimations of total emissions from POP approach for the countries not covered by the UWWTD database.

Figure 32 shows mean annual domestic emissions of Nitrogen (kg) per inhabitant (using the reference GHS2015 population). N emissions averaged 1.68 kg/inhabitant, but varied in the range 0.80 to 3.00, being higher for countries where adoption of secondary or tertiary treatment is still limited.

Mean annual Phosphorous emissions ranged from 0.07 to 0.77 kg/inhabitant (mean 0.31; Fig. 33). Phosphorous emissions per inhabitant were very low in countries where adoption of P removal technology is more frequent.

Mean annual BOD emissions due to domestic waste was 6.3 kg/inhabitant in Europe (Fig. 34), but the range of variability was very large, from 1 to 19 because of the large efficiencies gained in using secondary or higher treatment compared to no treatment or primary level only.

Figure 32. Estimated mean annual domestic waste emission of Nitrogen (kg/inhabitant/y) in Europe in the 2010s.

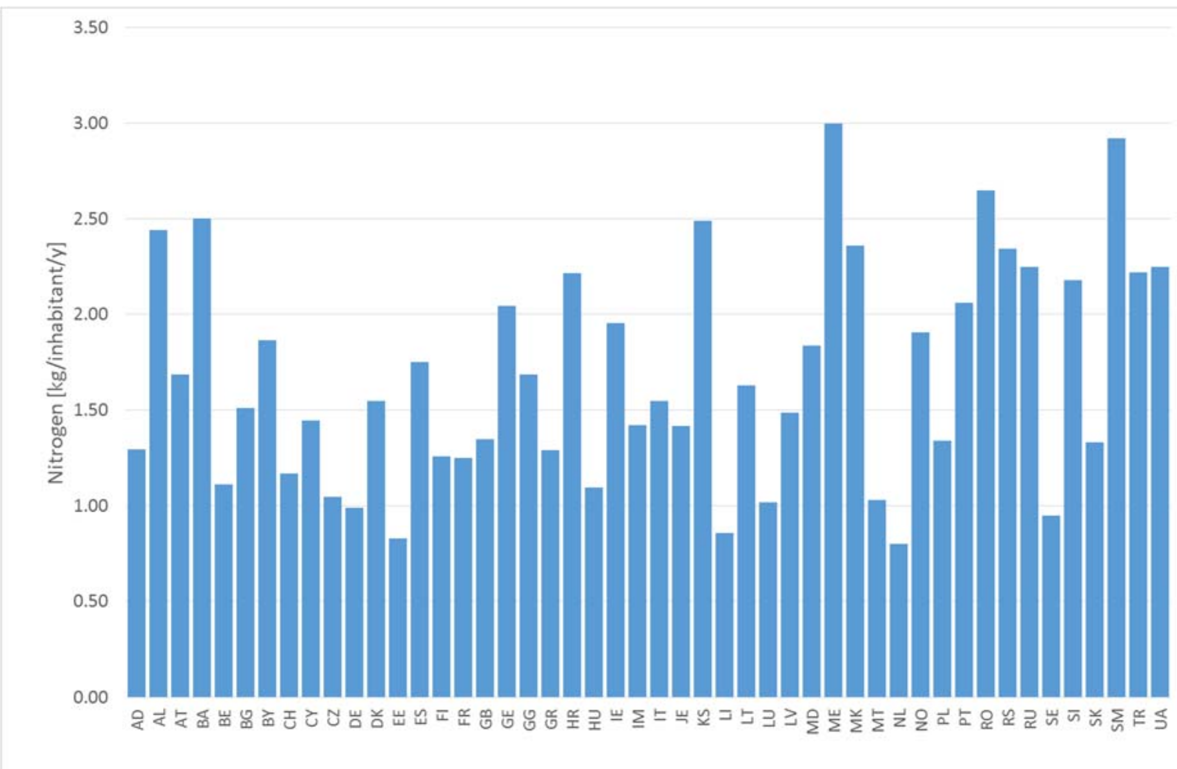


Figure 33. Estimated mean annual domestic waste emission of Phosphorous (kg/inhabitant/y) in Europe in the 2010s.

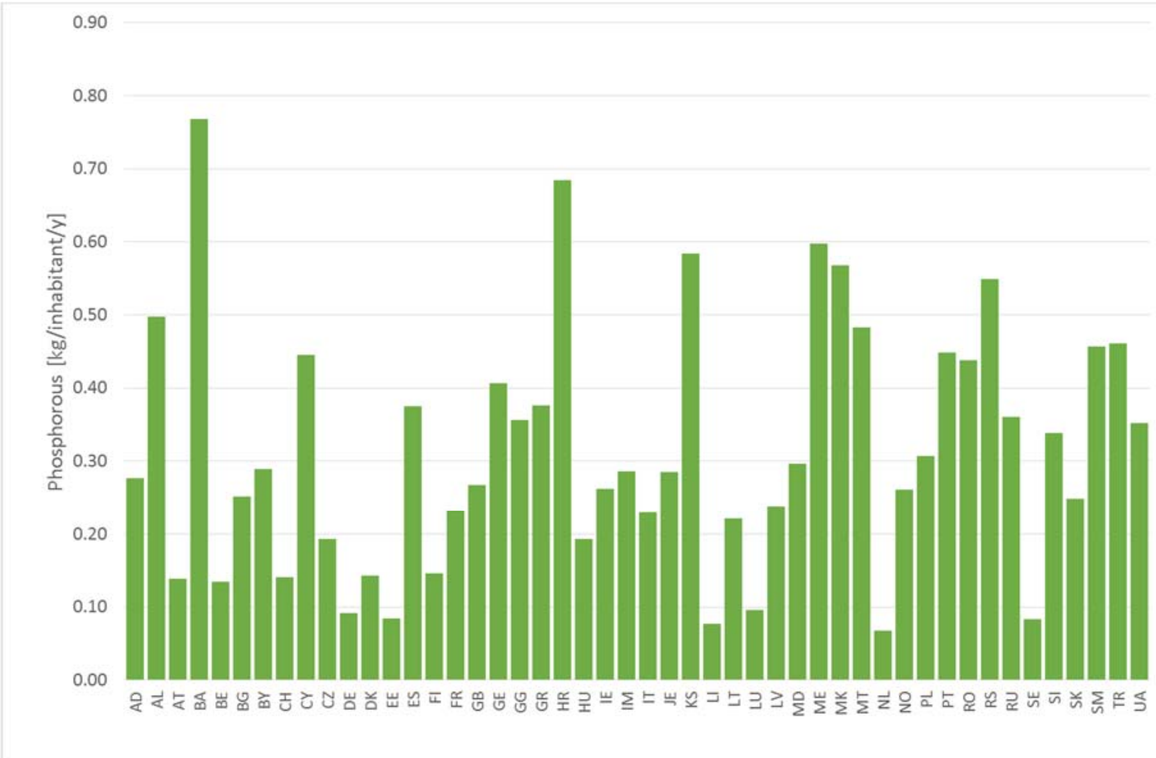
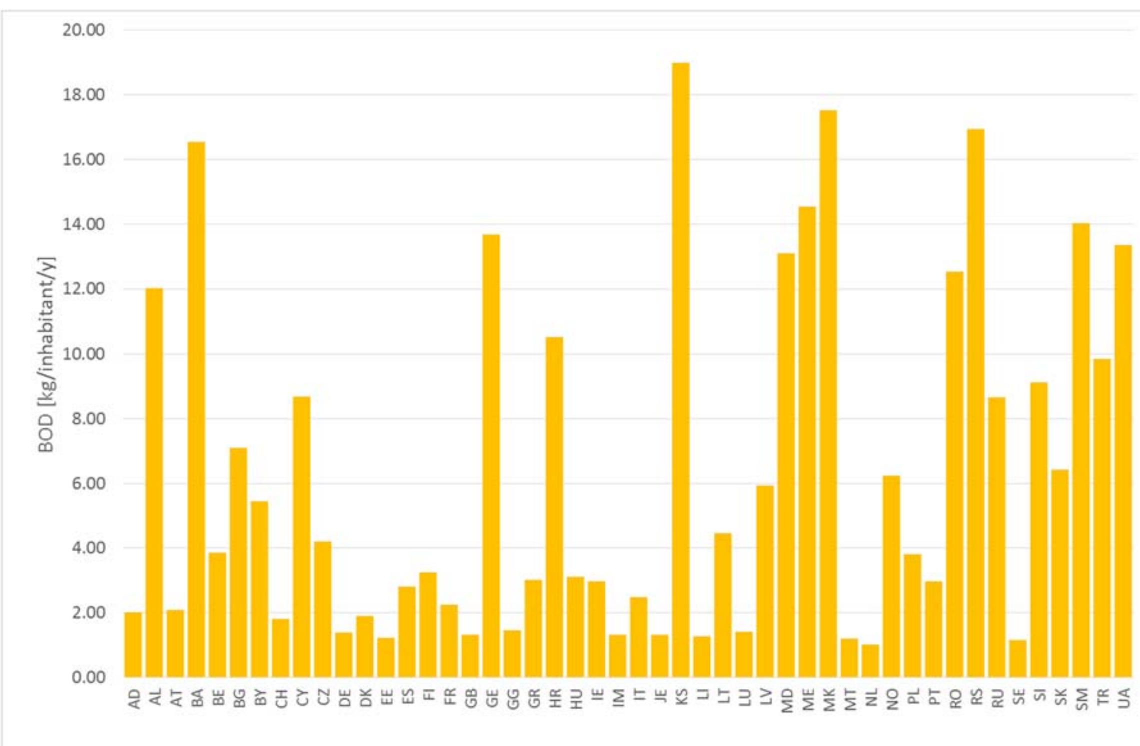


Figure 34. Estimated mean annual domestic waste emission of BOD (kg/inhabitant/y) in Europe in the 2010s.



3.4 Industrial emissions to water (IND)

Nitrogen, Phosphorous and BOD IND emissions reported in the E-PRTR database were largely variable, both as total per country and amounts per inhabitant (Figs 35-40). Across Europe, IND emissions of Nitrogen amounted to 193,500 t/y (13% of total emissions), whereas IND Phosphorous emissions were almost 24,353 t/y, about 10% of total emissions. BOD IND emissions totalled 1.52 M t/y and accounted for 27% of BOD total emissions. IND emissions were important point sources of pollution in AT, FI, GB, MT, NL, SE, but especially in NO, where IND emissions accounted for more than 90% of Nitrogen, Phosphorous and BOD emissions.

Industrial emission loads reported by NO were extremely high, more than 5 times higher than any other country; whereas emissions per capita were about 100 times larger than the average of all other countries. It is not clear if these data are reliable. The large majority (>95%) of these emissions are coming from aquaculture and located in coastal areas. As they are not discharged in freshwater systems, there is no monitoring data to evaluate the correctness of these emissions. Lacking alternative information to assess the reliability of these emissions, they were retained in this study.

When excluding NO, IND N emissions averaged 0.27 kg/inhabitant/y (median 0.14 kg/capita/y), with higher emissions per capita observed in RS, FI, GB, SE and MT (Fig. 36). P emissions averaged 0.02 kg/inhabitant/y (median 0.01) and were noticeably high in MT, GB and DK (Fig. 38). BOD emissions averaged 1.9 kg/capita/y (median 0.84) but were very large (>10 kg/capita) in (NO), FI and SE due to the importance of paper and forest industries (Fig. 40).

Industry emissions reported in the E-PRTR are however incomplete. First of all, only large facilities need to report in the register, thus emissions from small facilities are missing. Further, reporting of Nitrogen, Phosphorous and Organic Carbon emissions is voluntary, thus the completeness of E-PRTR entries cannot be assessed (AMEC, 2014). The number of industry facilities reported in the E-PRTR grows every reporting year; this is more likely an indication of improvement in the reporting than a reflection of industrial growth. van Duijnhoven and van den Roovart (2018) noted that the WWTPs reported in the E-PRTR were fewer (around 80%) than what should be reported considering large WWTP included in the UWWTD database. Similarly, emissions from pulp and paper industries appear to be under reported (AMEC, 2014).

IND considers thus only a portion of industrial emissions. An important share of industrial emissions is accounted for as part of the domestic waste load. Unfortunately, there is no further data to assess which proportion of domestic waste is industrial, nor if and to which extent industrial emissions to water are underestimated in this study. Industrial emissions remain a large source of uncertainty of emissions to waters currently.

Figure 35. Nitrogen annual emissions from Industries (IND), t/y. Y axis is cut at 30,000 t/y (NO entry is about 89,000 t/y).

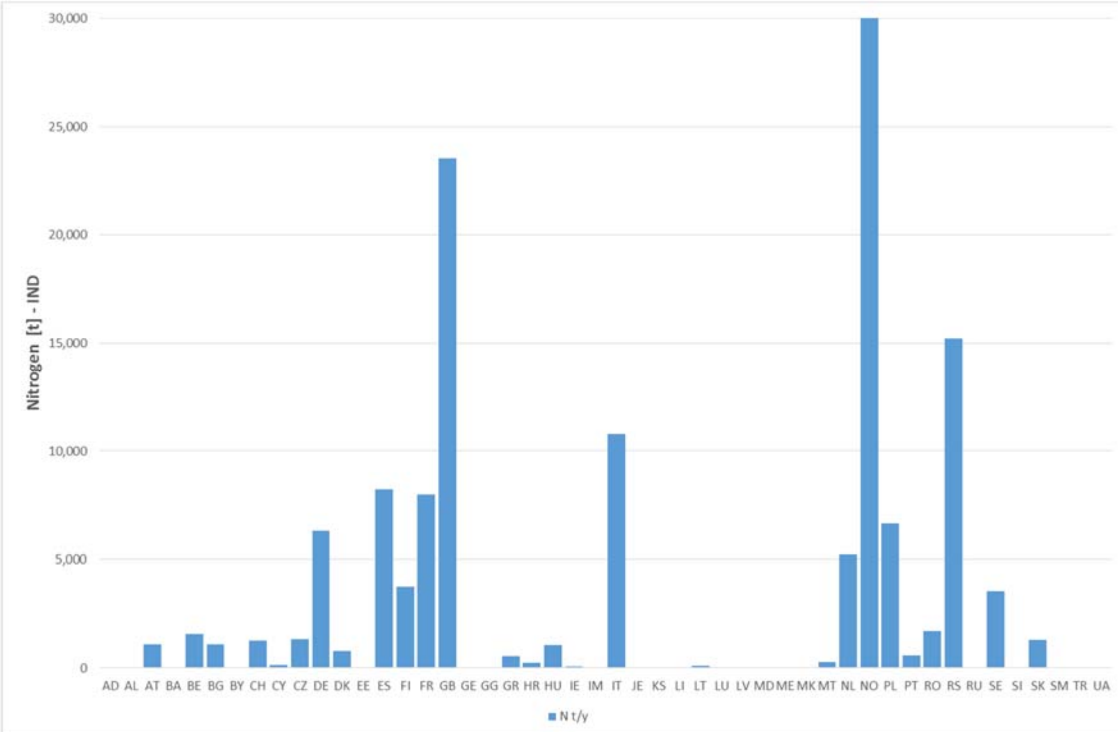


Figure 36. Mean annual Nitrogen annual emissions from Industries (IND) per inhabitant, kg/capita/y. Y axis is cut at 2.5 kg/capita/y (NO entry is 18 kg/capita/y).

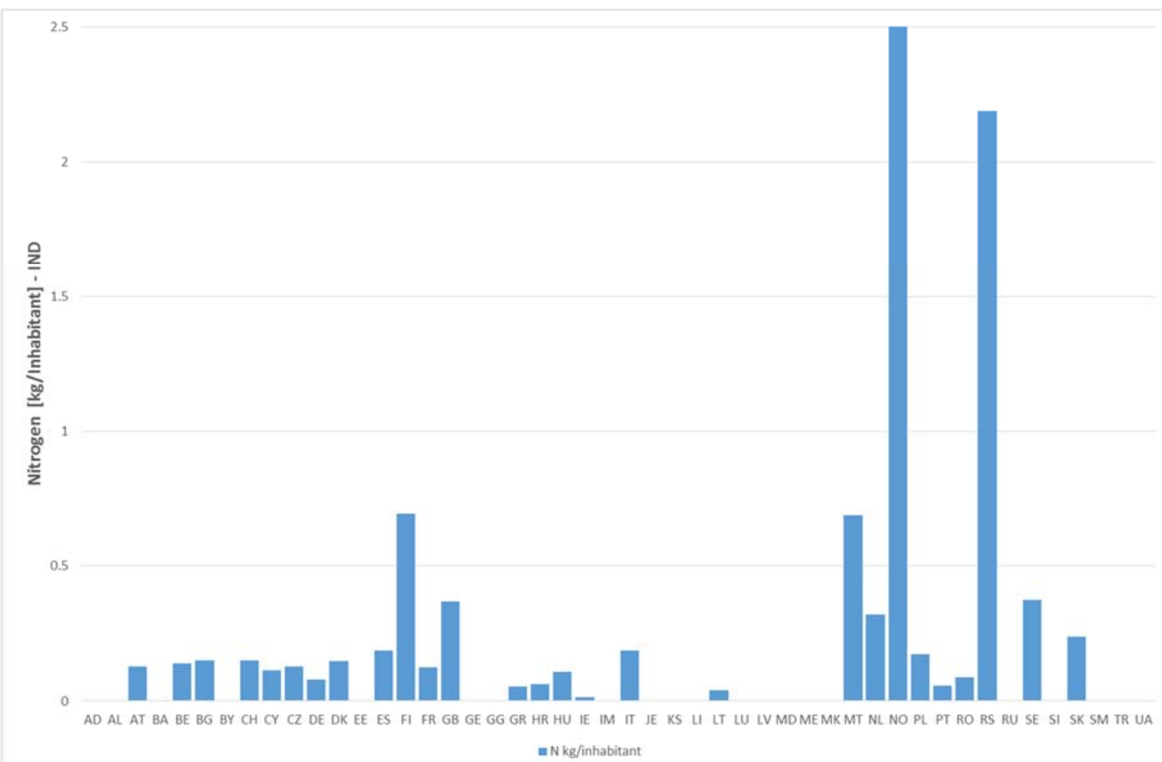


Figure 37. Phosphorous annual emissions from Industries (IND), t/y. Y axis is cut at 4,000 t/y (NO entry is about 15,000 t/y).

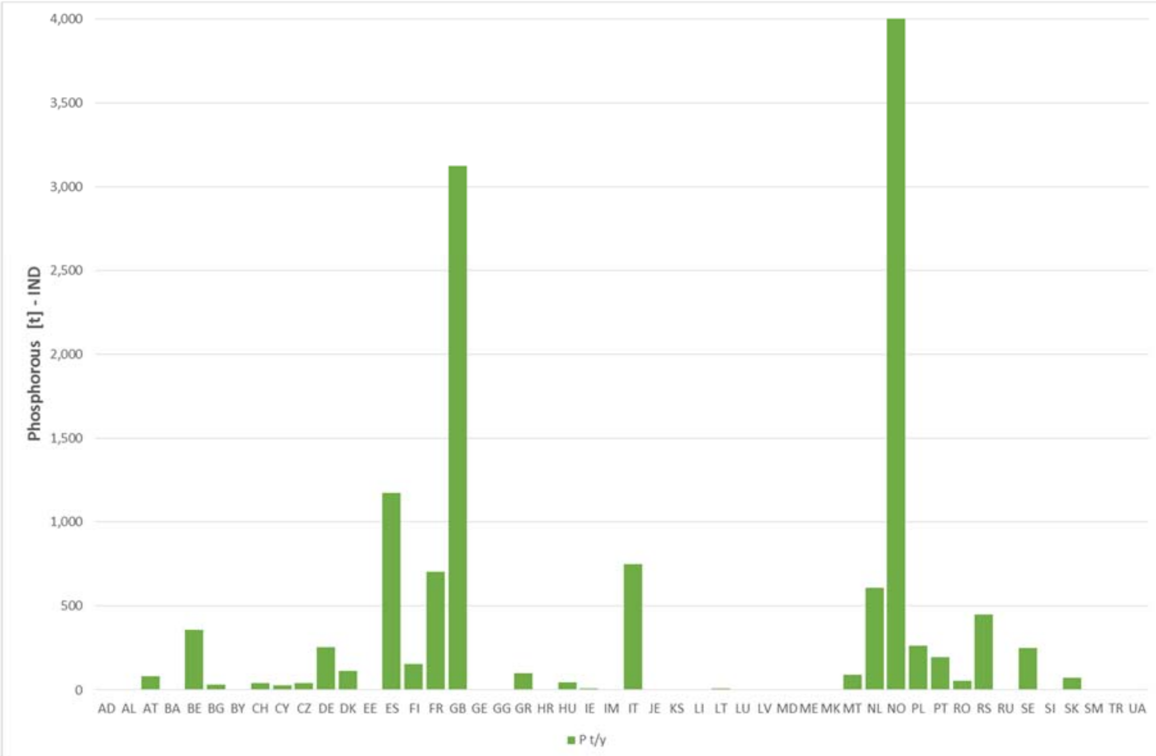


Figure 38. Mean annual Phosphorous annual emissions from Industries (IND) per inhabitant, kg/capita/y. Y axis is cut at 0.25 kg/capita/y (NO entry is 3.2 kg/capita/y).

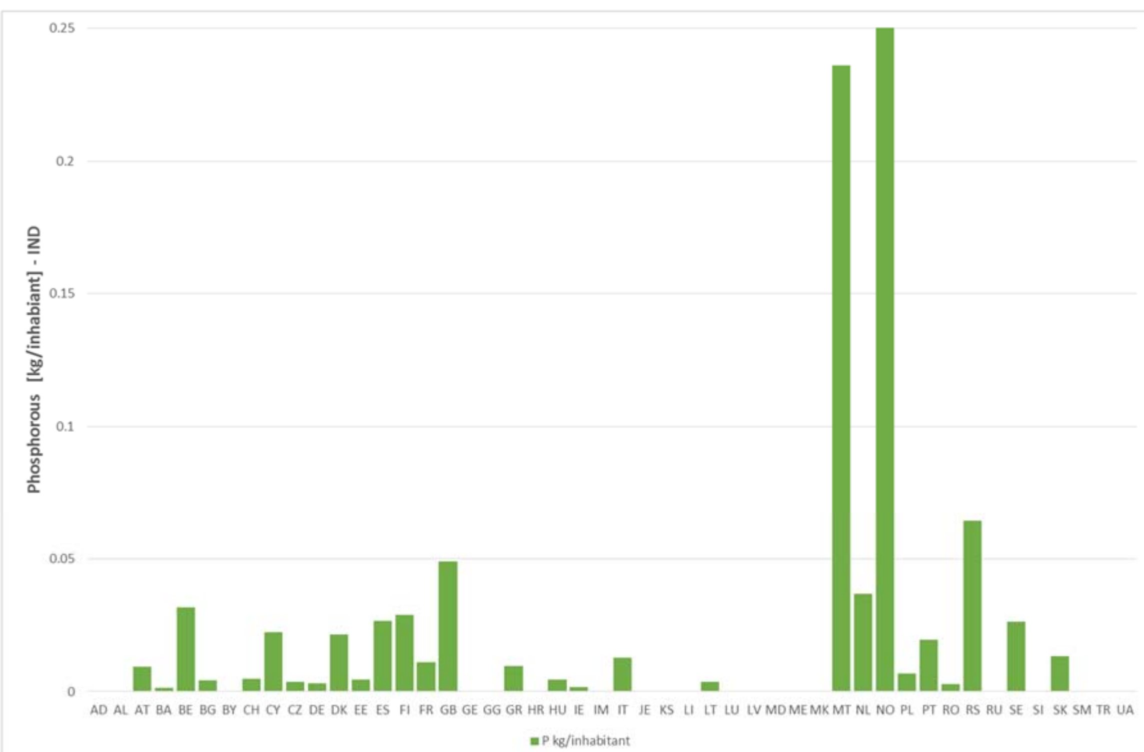


Figure 39. BOD annual emissions from Industries (IND), t/y. Y axis is cut at 250,000 t/y (NO entry is about 770,000 t/y).

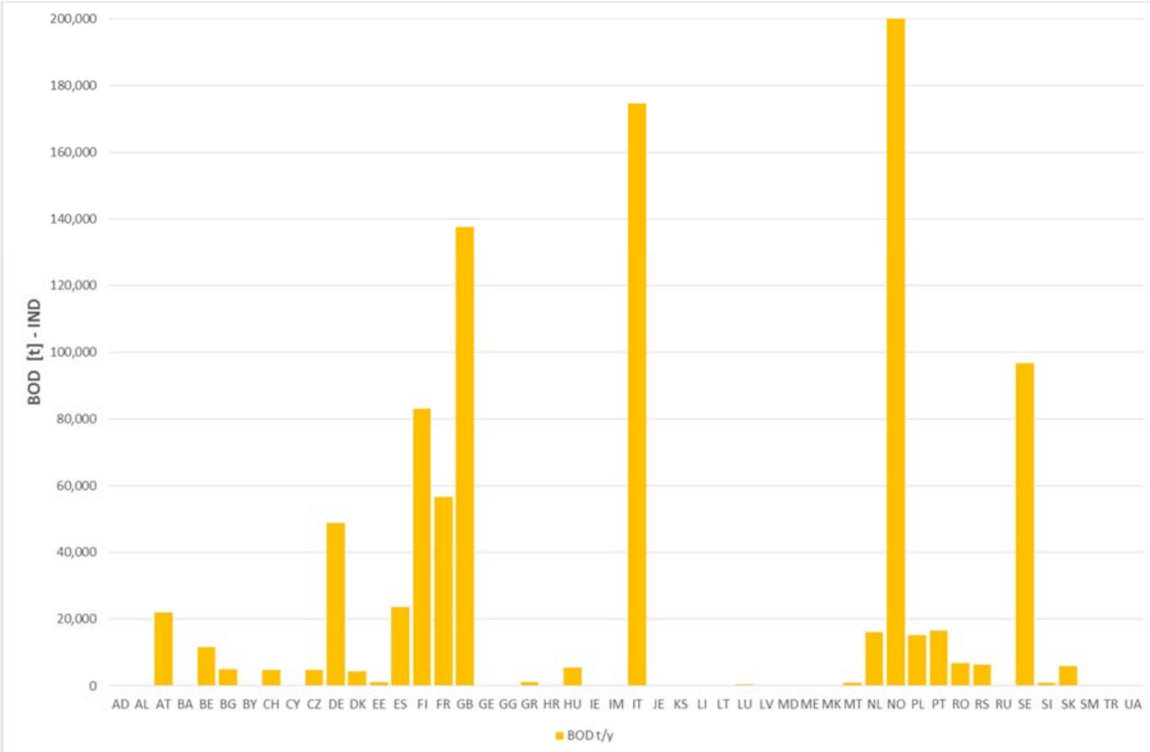
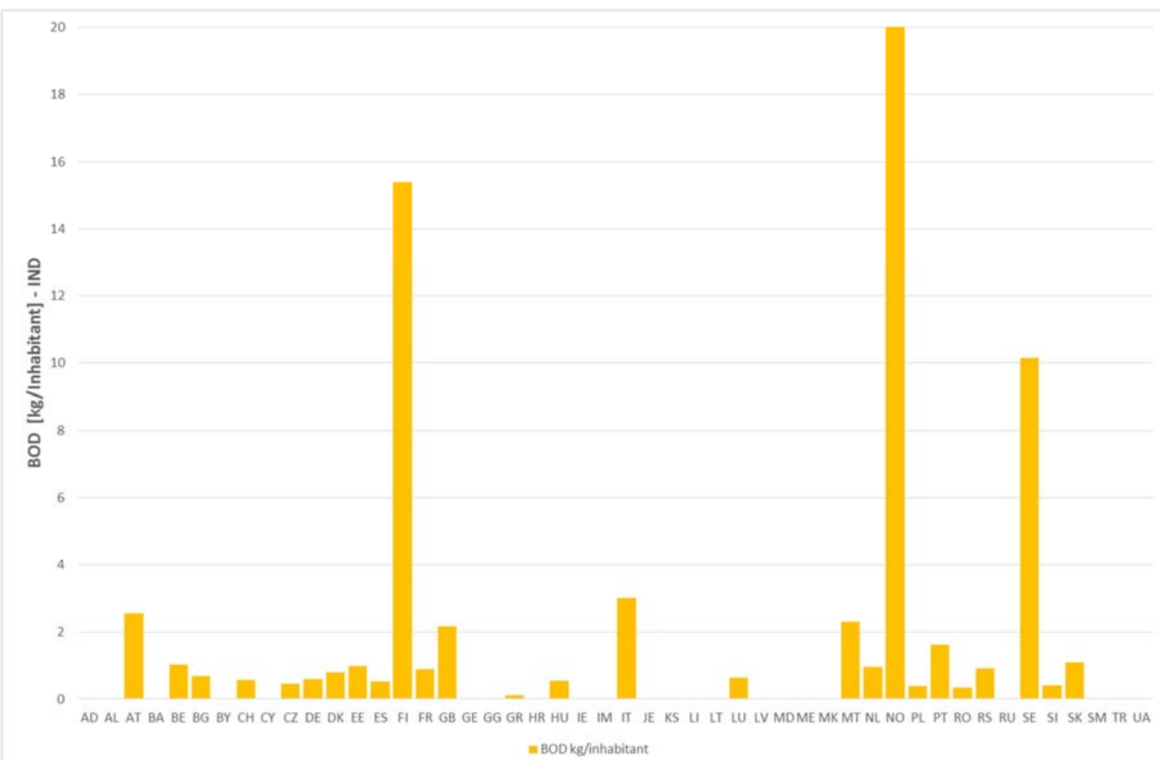


Figure 40. Mean annual BOD annual emissions from Industries (IND) per inhabitant, kg/capita/y. Y axis is cut at 20 kg/capita/y (NO entry is 163 kg/capita/y).



3.5 Total pollutant emissions across Europe in the 2010s

Figures 41-43 show total emissions of Nitrogen, Phosphorous and BOD estimated in this study across Europe (CCM2 extent). Domestic waste shares of emissions from scattered dwellings (SD), IAS, connected not treated population (0), connected and treated (T1-T3), and emissions from industries (IND) are indicated with different colours.

In EU28 emissions of Nitrogen and Phosphorous are largely coming from WWTPs discharges. In East Europe large domestic waste emissions remain from connected and untreated population. IND emissions are an important source of BOD point sources in EU28 countries, while connected not treated population remains a major source of organic pollution especially in East Europe. Table 7 summarizes total emissions of Nitrogen, Phosphorous and BOD assessed with this study for the 2010s across Europe (limited to the CCM2 extent) and for EU28.

Figure 41. Mean annual Nitrogen emissions (t/y) in Europe in the 2010s estimated in this study. N_SD are emissions from scattered dwellings; N_IAS from IAS; N_0 from connected not treated population; N_13 from connected and treated population; N_IND from industrial emissions.

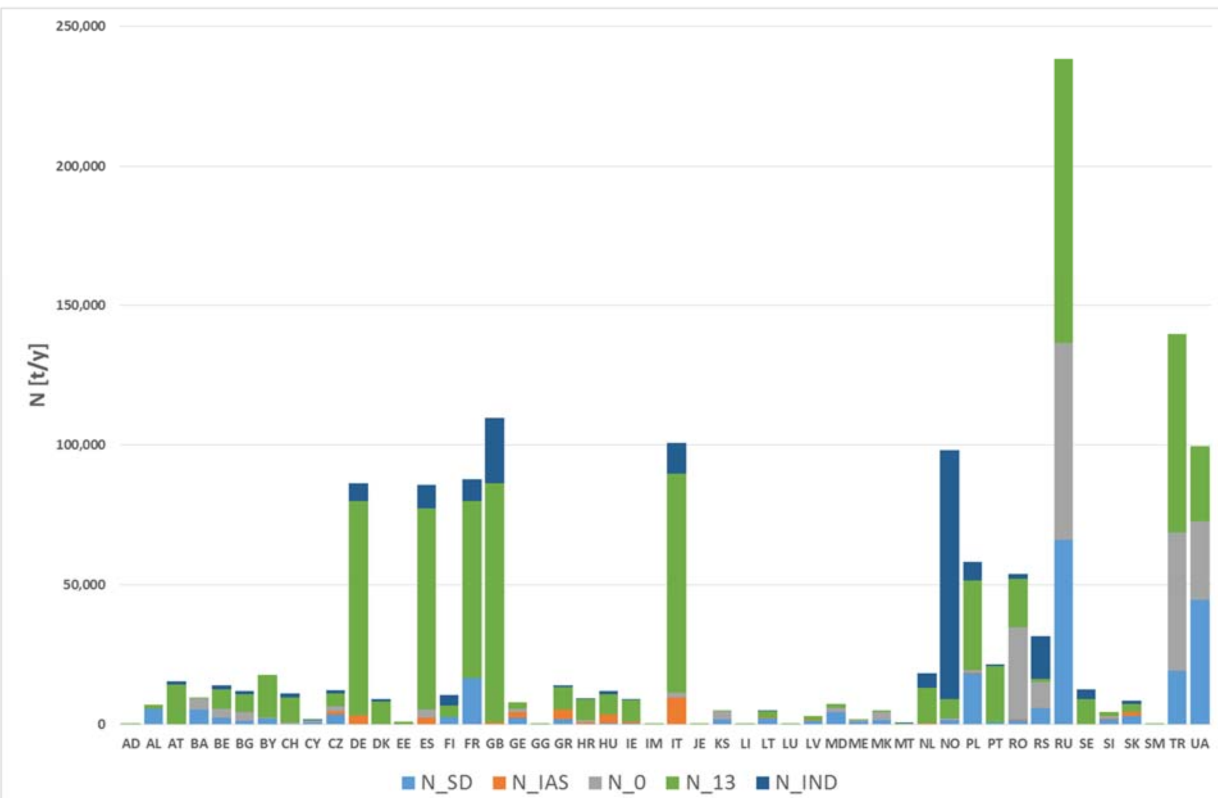


Figure 42. Mean annual Phosphorous emissions (t/y) in Europe in the 2010s estimated in this study. P_SD are emissions from scattered dwellings; P_IAS from IAS; P_0 from connected not treated population; P_13 from connected and treated population; P_IND from industrial emissions.

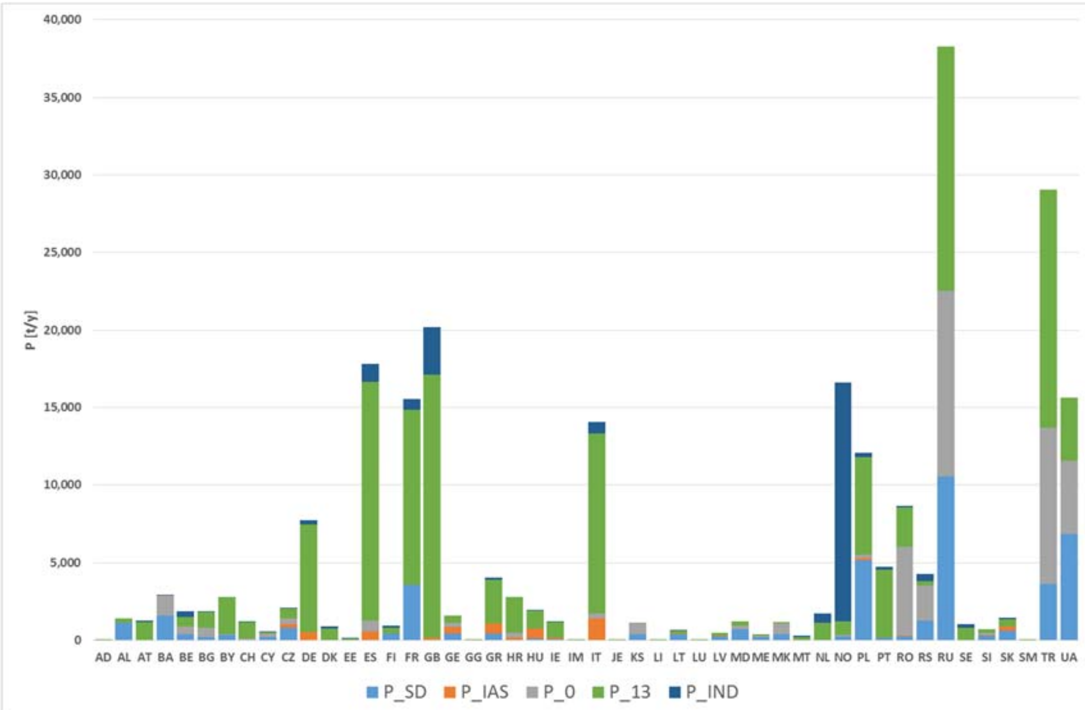


Figure 43. Mean annual BOD emissions (t/y) in Europe in the 2010s estimated in this study. BOD_SD are emissions from scattered dwellings; BOD_IAS from IAS; BOD_0 from connected not treated population; BOD_13 from connected and treated population; BOD_IND from industrial emissions.

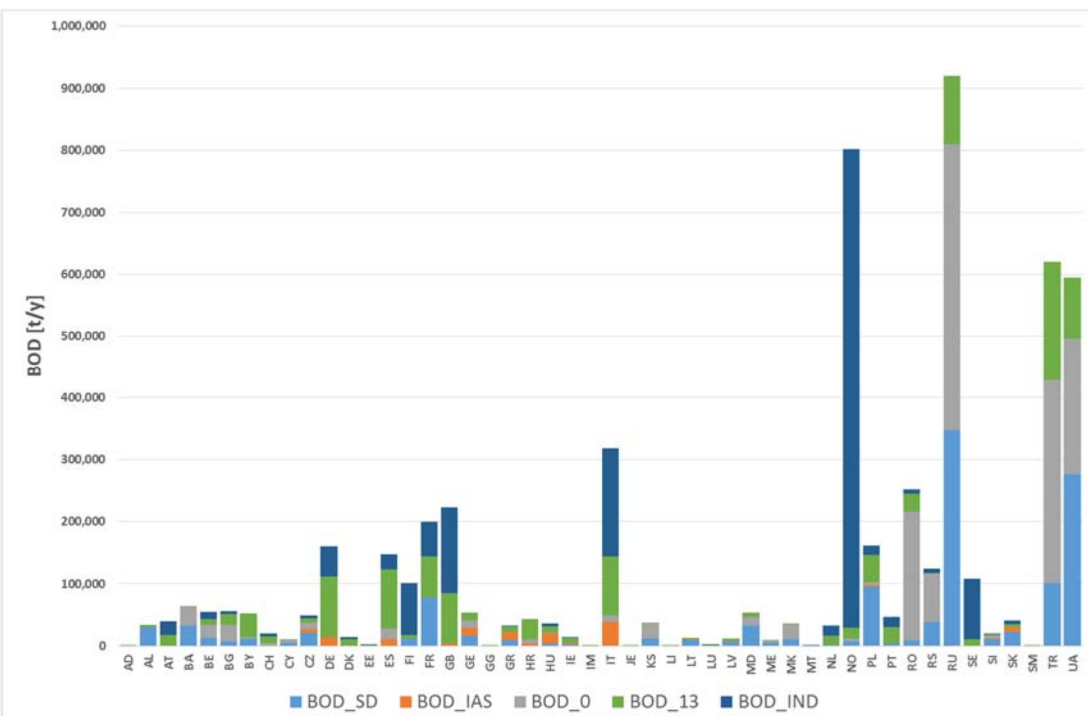


Table 7. Mean annual pollutant emissions (kt/y) estimated across Europe and for EU28 in the 2010s. DISC = disconnected population (scattered dwellings and IAS); T0 = Connected not treated population; T13 = WWTP discharges of connected and treated population; IND = industrial emissions.

	Nitrogen		Phosphorous		BOD	
	Europe	EU28	Europe	EU28	Europe	EU28
DISC	250 (17.2%)	87 (11.2%)	47 (19.1%)	18.4 (14.6%)	1,361 (24.3%)	428 (19.5%)
T0	221 (15.2%)	48 (6.2%)	42 (17.1%)	9.1 (7.2%)	1,520 (27.1%)	315 (14.4%)
T13	793 (54.4%)	554 (71.3%)	132 (53.9%)	90.6 (71.5%)	1,205 (21.5%)	709 (32.4%)
IND	194 (13.3%)	88(11.3%)	24 (10.0%)	8.5 (6.7%)	1,521 (27.1%)	738 (33.7%)
Total	1,458	777,6	244	126.6	5,607	2,190

Maps in figures 44-47 visualize the distribution in Europe of PE, Nitrogen, Phosphorus and BOD emissions. Spatially, pollutant emissions follow the distribution of population density. Figure 44 shows however that where urban centres are connected to high treatment WWTPs emissions loads are relatively less important than what could be derived from the population density only. National statistics overlap a pattern over that of population density, creating a sort of country border effect. For example, in FR an important share of scattered dwellings remains as part of the 'population residual' (POP_RES) that is not accounted for in the UWWTD database. Thus, domestic waste in FR appears more diffuse than in neighbour DE and ES, where POP_RES is nil and all domestic waste is located at agglomerations or WWTP discharge points, and results visually more concentrated.

Figure 44. Spatial distribution of PE in Europe (PE/km2) estimated in this study

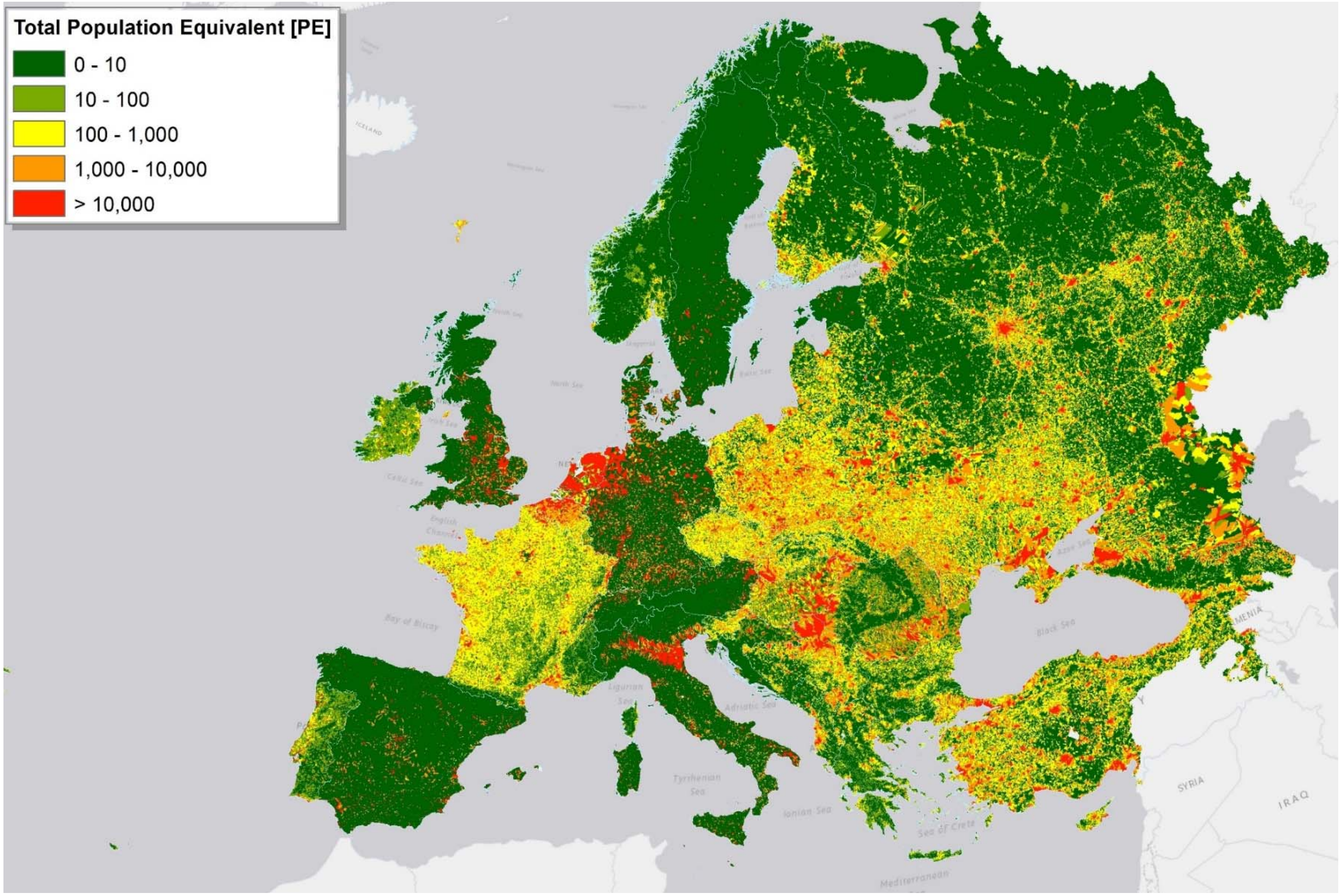


Figure 45. Spatial distribution of Nitrogen emissions to water across Europe (N kg/km2) estimated in this study

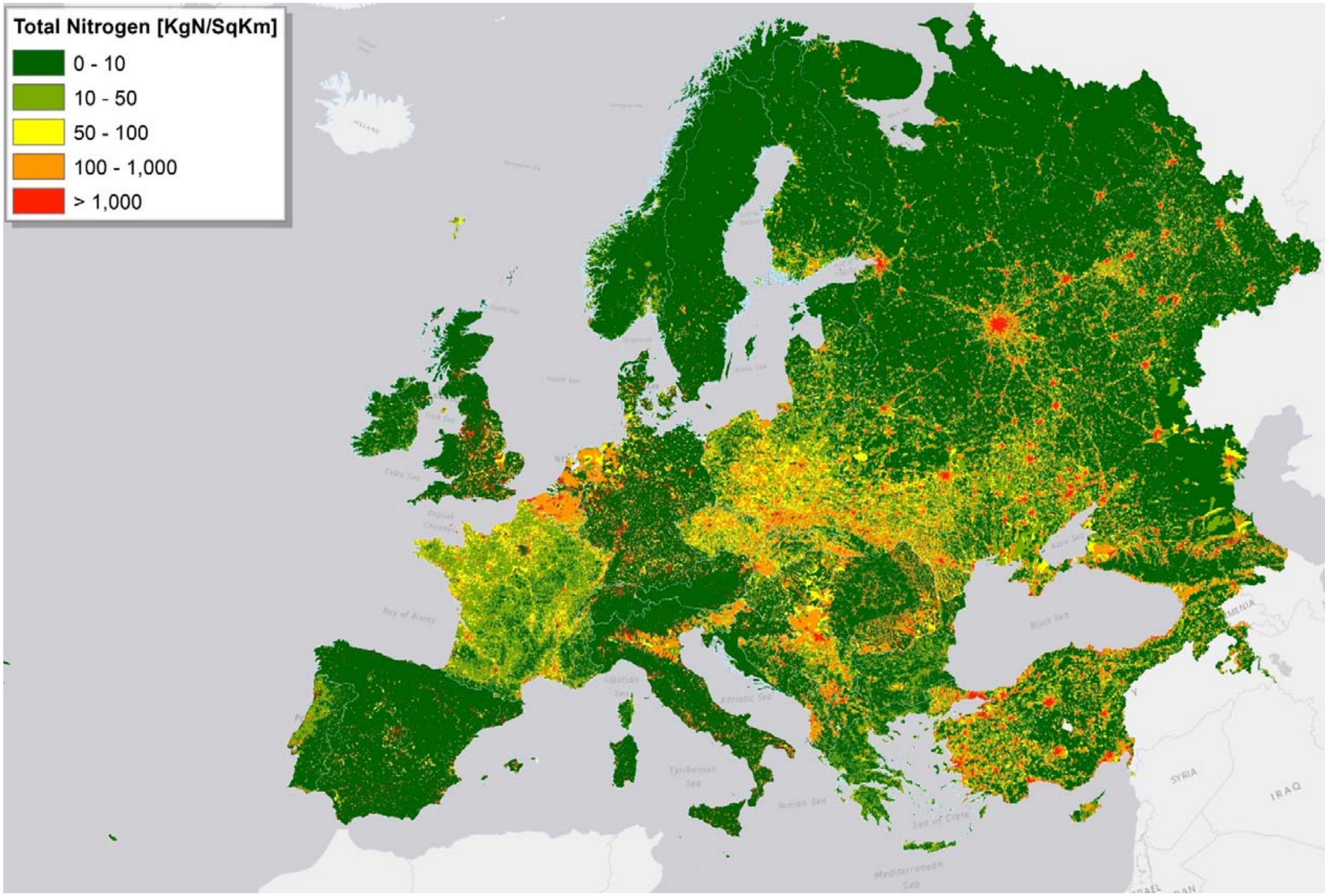


Figure 46. Spatial distribution of Phosphorous emissions to water across Europe (P kg/km2) estimated in this study

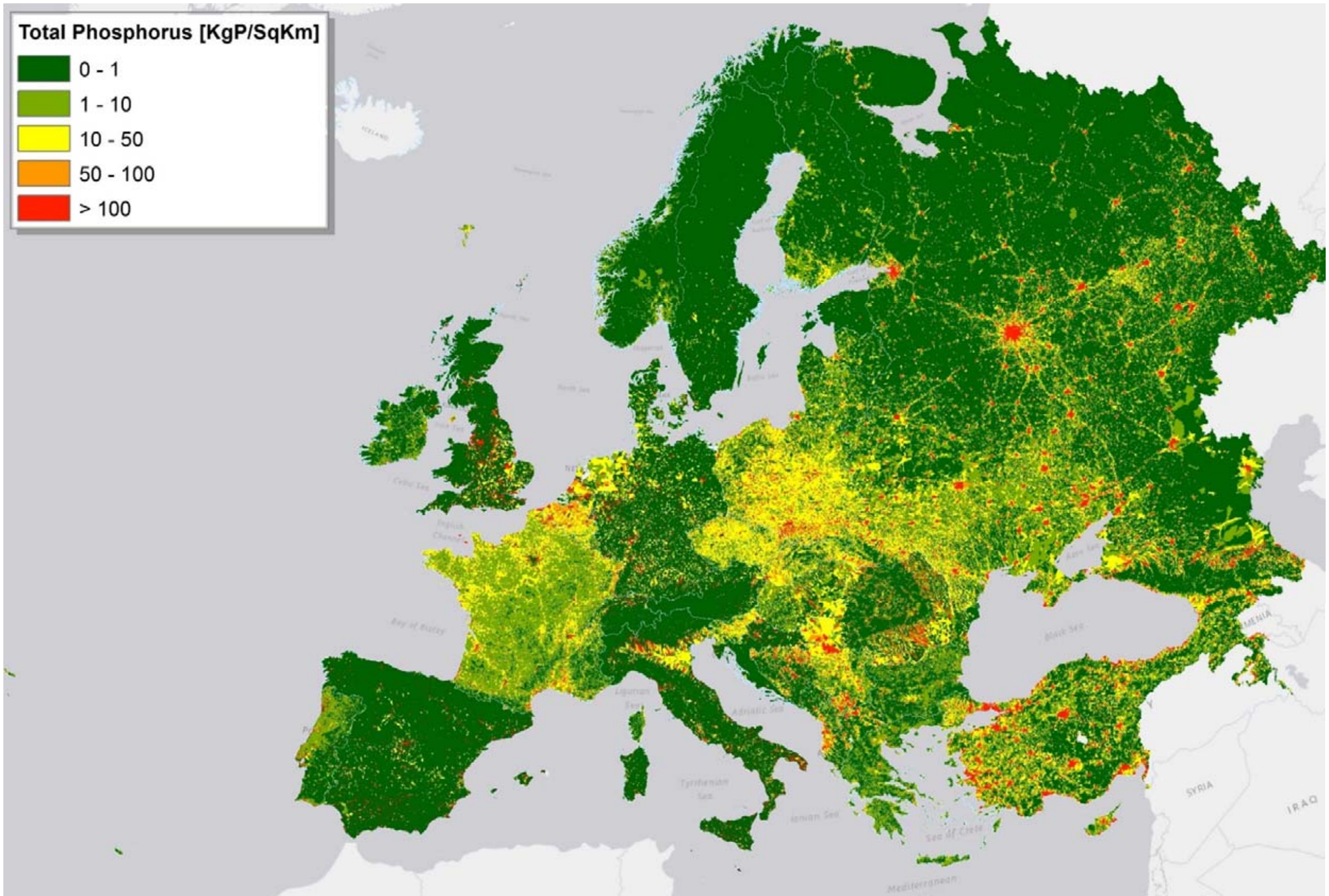
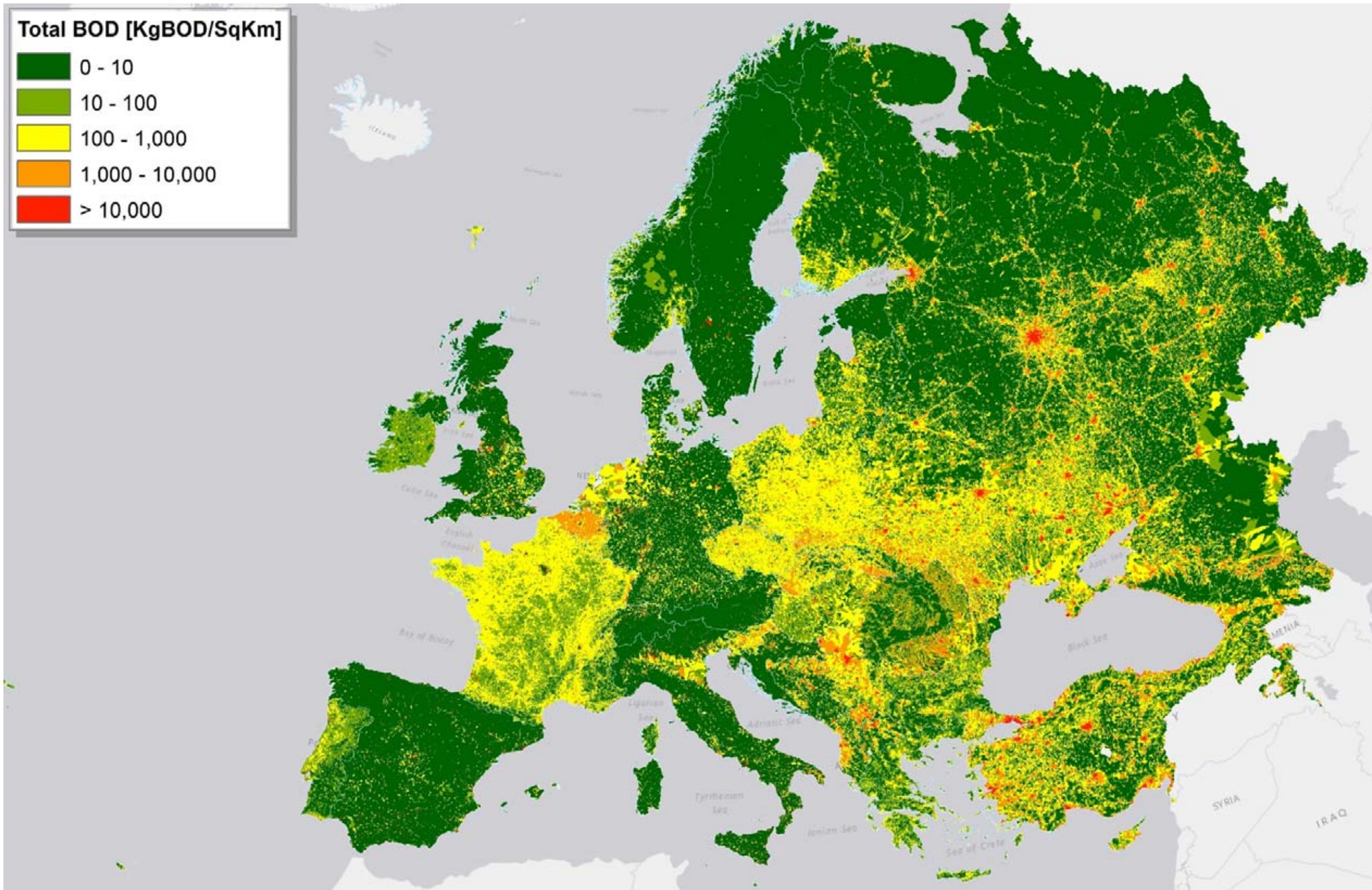


Figure 47. Spatial distribution of BOD emissions to water across Europe (BOD kg/km2) estimated in this study



4 Summary and conclusions

The assessment of pollutant loads (Nitrogen, Phosphorous and organic matter as measured by BOD) from domestic and industrial emissions to water across Europe for the 2010s made full use of available European databases created in response to EU regulations. A method was developed to exploit the European datasets and fill in content gaps through alternative sources of information (REP approach). The European datasets allowed pinpointing waste emissions to a much higher spatial and conceptual resolution than before, although some knowledge gaps remained. In particular, within EU28 large uncertainties concern emissions of Nitrogen, Phosphorous and organic matter (BOD) from domestic waste of small isolated dwellings and industries. Outside EU28, Switzerland and Norway, domestic emissions were assessed based on population density and national statistics of shares of population served by sewerage treatment and level of WWTP treatments (POP approach).

The comparison between Population Equivalent generated in agglomerations and reported in the UWWTD database with country resident population allowed estimating an equivalence of 1.23 PE per inhabitant, meaning that on average in Europe the contribution of small industries, commercial activities and tourism can be considered about 23% of generated waste. This information was used to assess population unreported in the UWWTD database because belonging to small isolated dwellings.

Estimates of total emissions due to domestic waste with REP approach with those from POP approach for 30 countries covered by both methods were in good agreement, with Pearson's correlation coefficient of 0.95 for Nitrogen, 0.94 for Phosphorous and 0.71 for BOD. Yet, important differences emerged when separating emissions by treatment type or pathway, e.g. looking at disconnected, connected not treated or connected and treated shares of domestic waste. The comparison highlighted inconsistencies between the European database and national statistics and it was noted that for some countries national statistics were scant or inconsistent. Thus, while total emissions are comparable, care should be taken when considering each share independently. Finally, total pollutant emissions for Europe in 2010s were obtained by merging all available data, using the REP approach and the POP approach estimates to fill in knowledge gaps.

In EU28, annual emissions to water from domestic and industrial waste for the 2010s were estimated at 777.6 kt/y of Nitrogen, 126.6 kt/y of Phosphorous and 2,190 kt/y of BOD. The majority of domestic waste is treated in WWTPs, with high adoption rates of tertiary treatment and Phosphorus removal technology, lowering emissions of domestic waste per capita. EU28 IND emissions accounted for 11.3% of N, 6.7% of P and 33.7% of BOD emissions. Emissions from population disconnected to sewerage systems or treated with IAS (for which only primary treatment was assumed) accounted for 11.2% of Nitrogen, 14.6% of Phosphorous and 19.5% BOD emissions to the environment. However only a part of these emissions would eventually reach freshwater systems, as environmental abatement (not considered in this study) would further reduce them. Conversely, connected not treated population contributed 6.2% of Nitrogen, 7.2% of Phosphorous, and 14.4% of BOD directly discharged to freshwater bodies. Tackling these sources of domestic waste and upgrading primary treatment facilities may further reduce pollution loads discharged in freshwater systems and ultimately to the seas.

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List of abbreviations and definitions

E-PRTR: European Pollutant Release and Transfer Register database (v13; EEA, 2018)

IAS - Individual Appropriate System: waste facility for small dwellings that are not served by sewerage network. IAS collects and treats domestic waste before releasing it to the environment or to a WWTP via truck transport. In this assessment waste from IAS are considered to be treated at primary level.

IAS/DISC – ratio of IAS population to disconnected population. The ratio is used to partition Pop_DISC into Pop_IAS and Pop_SD

IND - Industrial emissions: direct industrial emissions of waste to rivers.

PE - Person Equivalent: an amount of waste that equals to 60 g per day of BOD. This is the unit used in UWWTD database to report waste load.

PE_GEN: domestic waste PE generated in agglomerations as reported in the UWWTD database

PE_IAS: domestic waste treated in IAS, this is the net from what is transferred from agglomerations less what is transferred from IAS to UWWTP

PE_0: domestic waste that is generated in agglomerations but not treated (T0)

PE_WWTP: domestic waste that is treated in UWWTP, comprise also transfers from IAS.

POP: assessment of domestic waster emissions based on national statistics and population density

Pop_DISC: share of population whose waste is not collected in sewerage systems, comprise both Pop_SD and Pop_IAS; it is allocated to the least densely populated areas.

Pop_IAS: share of disconnected population that is served by IAS

Pop_SD: share of disconnected population that is served by septic tanks

Pop_0: share of population whose waste is collected in sewerage systems but not treated (T0)

Pop_1: share of population whose waste is collected in sewerage systems and treated at primary level (T1)

Pop_2: share of population whose waste is collected in sewerage systems and treated at secondary level (T2)

Pop_3: share of population whose waste is collected in sewerage systems and treated at tertiary level (T3)

Pop_3P: share of population whose waste is collected in sewerage systems and treated at tertiary level comprising Phosphorous removal technology (T3P)

Pop_RES: population not reported in the UWWTD database because belonging to small agglomerations of size less than 2000 PE. The amount of the population was estimated in this assessment by comparing reported PE and population at national level

Pop_RES_SD: the part of Pop_RES population that is disconnected from sewerage systems population (Scattered Dwellings)

Pop_RES_0: the part of Pop_RES population that is connected to sewerage systems but not treated

PopTot: total country population, estimated from GHS 2015 (CIESIN, 2015)

PRE - Population Resident Equivalents: the resident population (inhabitants) that generates 1 PE. In this study we assessed 1 PRE = 1 PE / 1.23. The interpretation of this equivalence is that on average across Europe the contribution of commercial, industrial and tourism emissions to domestic waste on top of resident population can be considered around 23%.

REP: assessment of domestic waste emissions based on data reported in the UWWTD database

SD - Scattered Dwellings: small, isolated households that are not connected to the sewer system but are generally equipped with septic tanks that remove part of the pollution load before the waste infiltrates underground.

T_DISC: upper population density threshold to define disconnected population Pop_DISC

T_0: upper population density threshold to define connected but not treated population Pop_0

T_1: upper population density threshold to define population connected to sewerage system and treated at primary level Pop_1

T_2: upper population density threshold to define population connected to sewerage system and treated at secondary level Pop_2; above this threshold density population was assumed connected to sewerage system and treated at tertiary level Pop_3

T0 - No treatment: domestic waste that is collected in sewerage systems but not treated before being discharged into rivers

T1 - primary treatment level of WWTP: mechanical removal of waste

T2 – secondary treatment level of WWTP: biological removal of waste

T3 – tertiary treatment level of WWTP: advanced removal of waste, may include technology for Phosphorous removal (T3P).

T3P - Tertiary treatment level of WWTP that includes Phosphorous removal technology, part of T3

T3P/T3: ratio of WWTPs at tertiary level that includes Phosphorous removal to all tertiary treatment plants, calculated at country level

TOC - Total Organic Carbon emission load to water reported for IND in the E-PRTR database. BOD was estimated from TOC based on molecular equivalence (BOD = 1.85TOC).

UWWTD database: database that reports domestic waste from 30 European Countries. In this assessment v6 that refers to data reported in 2014-2015 is used (EEA, 2017).

WWTP: Waste Water Treatment Plant

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Annex 1. Declared and derived population shares per treatment adopted in this study

Table A1.1 Percentage of population connected to sewers and to wastewater treatment levels adopted in the POP approach. Reference year was 2015, or closest possible (indicated in Data Year). Further explanations in the text.

			Pop 1	Pop 2	Pop 3	DISC	IAS/ DISC	Pop_SD	Pop_IAS	Pop_0	P/3ary	Pop_3P
Country	Collected (%)	IAS (%)	1 ary treatment (%)	2 ary treatment (%)	3 ary treatment (%)	%	fraction	%	%	%	fraction	%
Albania	19.0	NA	11.0	7.0	1.0	81.0	0	81.0	0.0	0.0	0	0.0
Austria	95.0	5.0	0.0	1.2	93.8	5.0	1	0.0	5.0	0.0	1	93.8
Belarus[1]	91.1	NA	25.7	64.7	0.0	8.9	0	8.9	0.0	0.7	0	0.0
Belgium	91.4	8.6	0.0	10.8	73.4	8.6	1	0.0	8.6	7.2	0.99	72.7
Bosnia Herz.	35.2	NA	0.1	1.2	0.6	64.8	0	64.8	0.0	33.3	0	0.0
Bulgaria	75.5	24.5	1.7	16.9	43.8	24.5	1	0.0	24.5	13.1	0.99	43.3
Croatia	54.6	45.4	16.0	35.9	1.0	45.4	0	0.0	45.4	1.7	1	1.0
Cyprus	29.8	70.2	0.0	4.7	25.1	70.2	1	0.0	70.2	0.0	0.90	22.7
Czech Republic	85.2	2.4	0.2	6.9	73.9	14.8	0.16	12.4	2.4	4.2	0.96	71.0
Denmark	91.0	9.0	0.0	2.0	89.0	9.0	1	0.0	9.0	0.0	1	89.0
Estonia	83.0	5.0	0.0	5.0	78.0	17.0	0.29	12.1	4.9	0.0	1	78.0
Finland	83.0	17.0	0.0	0.0	83.0	17.0	1	0.0	17.0	0.0	1	83.0
France	82.1	18.0	0.1	14.3	66.1	17.9	1	0.0	17.9	1.6	0.86	56.5
Georgia	44.2	23.4	28.6	3.3	0.2	55.8	0.42	32.4	23.4	12.1	0	0.0

Germany	96.2	3.2	0.0	2.5	92.9	3.8	0.84	0.6	3.2	0.8	0.98	91.2
Greece	92.9	0.0	0.0	3.6	89.3	7.1	0	7.1	0.0	0.0	0.27	24.2
Hungary	78.8	NA	0.1	12.2	64.6	21.2	0	21.2	0.0	1.9	0.95	61.5
Iceland	91.0	7.0	65.0	0.0	1.0	9.0	0.78	2.0	7.0	25.0	0	0.0
Ireland	69.0	31.0	0.0	47.0	18.0	31.0	1	0.0	31.0	4.0	0.96	17.4
Italy	94.0	NA	2.9	18.7	40.9	6.0	0	6.0	0.0	31.5	0.70	28.7
Kosovo*	54.3	0.0	0.0	0.6	0.0	45.7	0	45.7	0.0	53.7	0	0.0
Latvia	71.1	28.9	3.7	50.0	17.2	28.9	0	0.0	28.9	0.2	1	17.2
Lithuania	72.5	NA	0.1	6.9	65.4	27.5	0	27.5	0.0	0.1	1	65.4
Luxembourg	98.2	1.8	1.8	25.2	71.2	1.8	0	0.0	1.8	0.0	1	71.2
Macedonia, FYR	60.0	NA	6.5	6.5	0.0	40.0	0	40.0	0.0	47.0	0	0.0
Malta	98.6	0.0	6.4	92.2	0	1.4	0	1.4	0.0	0.0	0	0.0
Moldova	38.0	NA	12.0	12.0	0.0	62.0	0	62.0	0.0	14.0	0	0.0
Montenegro	43.0	NA	9.0	9.0	0.0	57.0	0	57.0	0.0	25.0	0	0.0
Netherlands	99.4	0.6	0.0	1.0	98.4	0.6	1	0.0	0.6	0.0	0.98	96.0
Norway	86.2	13.8	18.1	1.6	64.1	13.8	1	0.0	13.8	2.4	1	64.1
Poland	72.6	NA	0.0	13.7	58.9	27.4	0	27.4	0.0	0.0	0.99	58.7
Portugal	81.3	5.0[#]	3.6	39.4	16.4	18.7	0.27	13.7	5.0	21.9	0.76	12.5
Romania	47.8	1.9	6.3	14.7	24.9	52.2	0.04	50.1	2.1	1.9	0.96	23.8
Russian Fed.	75.0	NA	2.0	54.0	1.0	25.0	0	25.0	0.0	18.0	0	0.0
Serbia	58.7	NA	1.3	8.7	1.9	41.3	0	41.3	0.0	46.8	0	0.0
Slovenia	62.6	35.2	0.0	30.5	27.1	37.4	0.94	2.2	35.2	5.0	1	27.1
Slovak Republic	65.2	NA	0.1	33.0	31.4	34.8	0	34.8	0.0	0.7	0.92	29.0
Spain	97.2	1.5	1.7	23.9	69.0	2.8	0.54	1.3	1.5	2.6	0.79	54.4

Sweden	87.0	13.0	0.0	4.0	83.0	13.0	0	0.0	13.0	0.0	1	83.0
Switzerland	98.3	1.7	0.0	11.0	87.0	1.7	0	0.0	1.7	0.3	1	87.0
Turkey	87.0	0.0	20.9	24.8	18.4	13.0	0	13.0	0.0	22.9	0	0.0
Ukraine	52.7	NA	16.2	16.2	0.0	47.3	0	47.3	0.0	20.3	0	0.0
United Kingdom	100.0	NA	0.0	43.0	57.0	0.0	0	0.0	0.0	0.0	0.92	52.7

*under United Nations Security Council Resolution 1244/99

Disconnected population: DISC = 100- Collected%; Ratio of IAS in Disconnected population = IAS/DISC = IAS%/DISC; P/3ary: fraction of tertiary treatment with P removal, based on UWWTD database information.

Pop_SD = population in Scattered Dwellings = DISC * (1-IAS/DISC); Pop_IAS = population disconnected to sewerage but served by IAS = DISC * IAS/DISC; Pop_0 = Population collected and not treated = Collected – (Pop_1+Pop_2+Pop_3); Pop_3P = Population in tertiary treatment with P removal = Pop_3 * P/3ary

Annex 2. Treatment levels of European Cities in the 1990s

Table A2.1 Anecdotal evidence about treatment level serving major European towns in the 1990s (Psomas and Ronen, 2018).

Country	ISO 3166.1	Not treated	1ary treatment	2ary treatment	3ary treatment
Albania	AL	Tirana and other big cities			
Austria	AT			Graz, Klagenfurt, Krems, Linz, Pöls, Raum Gratkorn, Villach, Welser Heide, Vienna and Vienna Neustadt; also probably partly those having tertiary in 1998: Wien, Linz, Salzburg, Bregenz, Dornbirn, Feldkirch, Hohenems, Innsbruck, Lenzing, Schwaz, St Pölten, Steyermüh	In 1998: Wien, Linz, Salzburg, Bregenz, Dornbirn, Feldkirch, Hohenems, Innsbruck, Lenzing, Schwaz, St Pölten, Steyermüh
Belgium	BE	Brussels, Liege (partly), Charleroi (partly)		in the region of Flanders; partly in: Liege and Charleroi	
Bulgaria	BG			Sofia, Plovdiv, Burgas, Varna	
Croazia	HR	Zagreb			
Switzerland	CH			Zurich, Bern	
Cyprus	CY	Nicosia, Limassol			
Czech Republic	CZ			Prague and other big cities	
Denmark	DK				Aalborg, Aarhus, Fredericia, Copenhagen and Odense
Estonia	EE		Tallin	Rakvere, K-Järve	
Finland	FI				Helsinki, Espoo, Jyväskylä, Lahti,

					Tampere and Turku
France	FR		Lille, Marseille and Bordeaux	Paris (partly)	in 1998: Angers, Besançon, Cholet, Colmar, Douai, Metz, Nantes and Royan; Paris (partly)
Greece	GR	Patra, Elefsina, Aspropyrgos, Athens		Iraklio, Metamorphosi, Thessaloniki	
Hungary	HU	Szeged		Debrecen, Budapest (partly)	Budapest (partly)
Iceland	IS	Reykjavík			
Ireland	IE	Cork, Dundalk	Dublin		
Italy	IT	Foce Sarno, Imperia Foce Impero, Medio Sarno, Merano, Milan, Misterbianco and Taranto	partly in: Florence, Reggio Calabria and Trieste	partly in: Florence, Reggio Calabria and Triest; fully in: Bologna, Cagliari, Catania, Genoa, Modena, Monza, Naples, Padua, Rimini, Turin and Venice; also probably partly in those having tertiary in 1998: Bari, Bergamo, Brescia, Livorno, Messina, Palermo, Parma, Ravenna, Rome and Verona	in 1998: Bari, Bergamo, Brescia, Livorno, Messina, Palermo, Parma, Ravenna, Rome and Verona
Latvia	LV			Riga	
Lithuania	LT	Kaunas	Vilnius, Klapeida		
Luxembourg	LU			Luxembourg city	
Malta	MT			Marsa land, Malta South	
Netherlands	NL			Amsterdam, Eindhoven, Hague, Rotterdam, Haarlem, Arnhem and Rotterdam	
Norway	NO				Oslo

Poland	PL	Lodz	Gdansk (partly)	Warsaw, Gdansk (partly)	
Portugal	PT	Barreiro, Costa do Estoril, Cova da Beira, Matosinhos, Porto, Setúbal and Vila Nova de Gaia	partly in: Aveiro and Lisbon	partly in: Aveiro and Lisbon; fully in: Loures/Frielas and São João de Talha; also probably partly in those having tertiary in 1998: Faro, Sistema de Alcanena and Vilamoura	in 1998: Faro, Sistema de Alcanena and Vilamoura
Romania	RO	Bucharest, Craiova, Drobeta-Turnu-Severin, Braila, Galati, Tulcea			
Serbia	RS	Belgrade, Niš and Novi Sad			
Slovak Republic	SK			in big cities	
Slovenia	SI		Ljubljana		
Spain	ES	La Coruña, Alginet, Cadiz, Donostia-San Sebastian, Gijon, Logroño, Tui	Barcelona	Madrid, Seville, Valencia; also probably partly those having tertiary in 1998: Alméria, Bilbao, Calvia, Oviedo, Valladolid, Vitoria-Gasteiz Xirivella and Zaragossa	in 1998: Alméria, Bilbao, Calvia, Oviedo, Valladolid, Vitoria-Gasteiz Xirivella and Zaragossa
Sweden	SE				in 1998: Stockholm, Kristianstad, Malmö, Helsingborg, Gothenburg, Lidingö, Lingkoping
Turkey	TR		Istanbul (partly)	Istanbul (partly)	
United Kingdom	GB	Dundee, Sunderland/Whitburn, Middlesbrough, Hull,Bedington, Port Talbot, Torbay, Portsmouth, Brighton,	Aberdeen, Glasgow, Edinburgh, Newcastle upon Tyne, Liverpool, Great Yarmouth, Cardiff,	London and 60 more big cities	in 1998 fully in: Milton Keynes and Coventry; in 1998 partly in: London and 60 more big cities;

		Hastings, Dover/Folkestone	Bristol, Sandown, Worthing, Gillingham, Eastbourne		
Russian Fed.	RU			in big cities	
Ukraine	UA			in big cities	
Belarus	BY		partly in: Minsk, Brest, Grodno	partly in: Minsk, Brest, Grodno	
Moldova	MD			Chisinau	
Georgia	GE	Tbilisi and other big cities			
Macedonia, FYR	MK	Skopje			
Montenegro	ME			Podgorica (partly)	

Figure A.2.1. Flow chart part 1: country GHS2015 population density cumulative distribution was put in relation to national statistics to derive country population density thresholds.

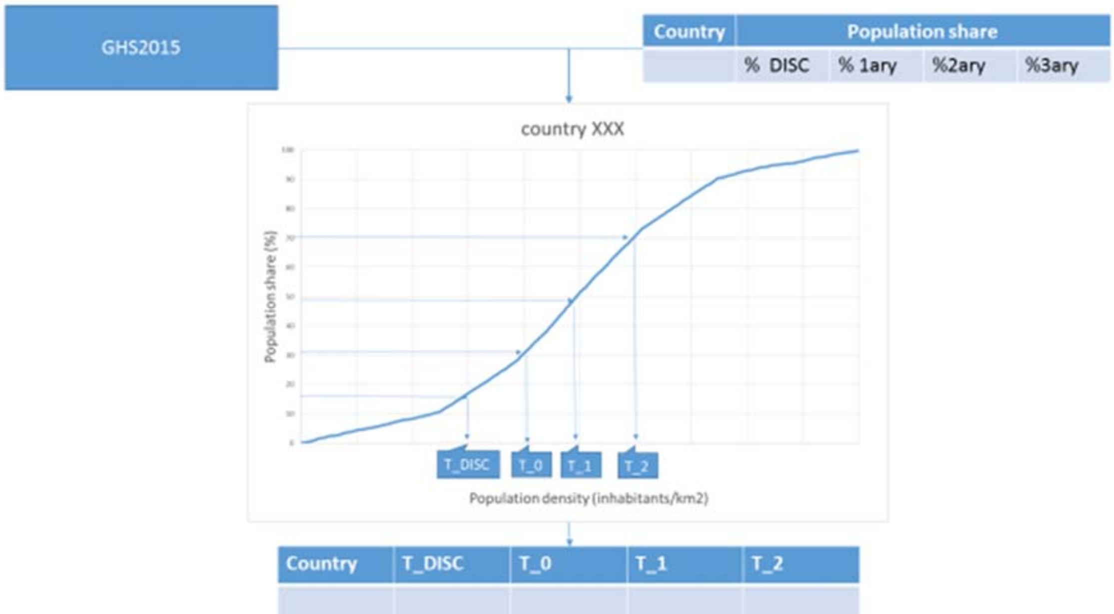


Figure A.2.2. Flow chart part 2: country population density thresholds were applied to GHS2015 population density to derive density maps per treatment level. These were resampled to 100 m resolution. Zonal statistics was used to calculate mean population density per treatment and per CCM2 catchment.

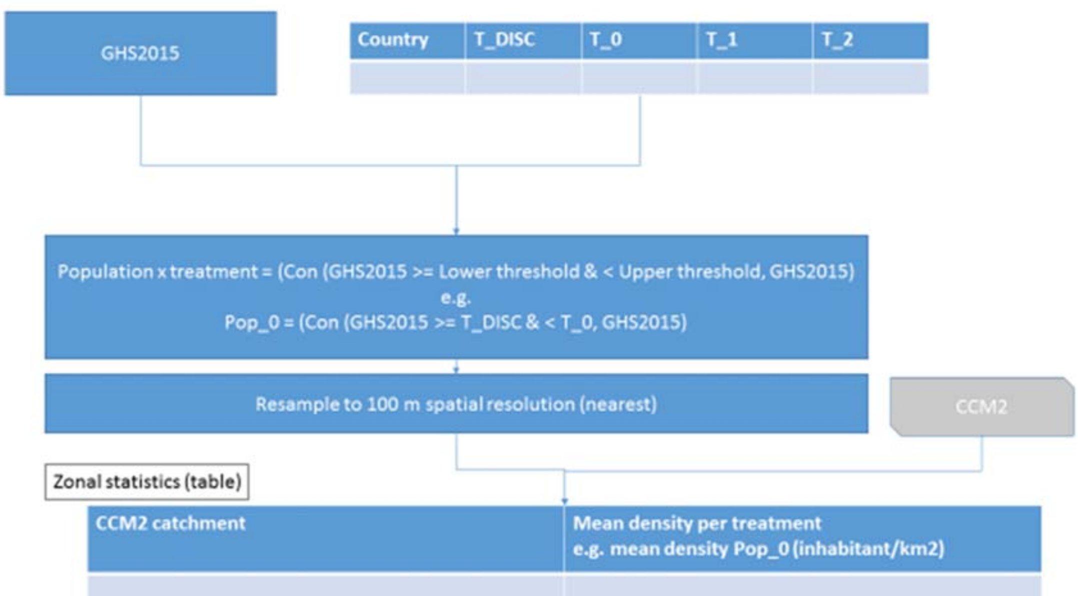


Table A2.2 Upper density population thresholds (inhabitants/km^2) applied to identify population receiving each treatment level. Lower thresholds corresponds to Upper threshold of the class to the left.

Country	ISO 3166.1	Disconnected T_DISC	Connected Not treated T_0	Primary treatment T_1	Secondary treatment T_2
Albania	AL	8712	8712	14754	16794
Austria	AT	52.86	52.86	52.86	63.87
Belarus	BY	259	282	2291	NA
Belgium	BE	194.43	319.6	319.6	519.37
Bosnia Her	BA	3189	9618	9995	15092
Bulgaria	BG	451	806	851	1712
Croazia	HR	803	863	1668	7527
Cyprus	CY	2815	2815	2815	3040
Czech Republic	CZ	196.4	254.6	258.5	374
Denmark	DK	85.5	85.5	85.5	110
Estonia	EE	175	175	175	285
Finland	FI	366	366	366	366
France	FR	213.5	238	240	545.5
Georgia	GE	2014	3737	14874	16719
Germany	DE	81.5	96	96	137.5
Greece	GR	98.5	98.5	98.5	151
Hungary	HU	371.5	413.5	415	730
Iceland	IS	193	1373	7019	7019
Ireland	IE	258	333	333	3790
Italy	IT	136.7	1004	1118	2029
Latvia	LV	981	993	1181	4892
Lithuania	LT	999	1002	1007	1448
Luxembourg	LU	36	36	61	439
Macedonia, FYR	MK	1446	5970	7184	NA
Malta	MT	140	140	575	NA
Moldova	MD	1442	2456	4256	NA
Montenegro	ME	1954	4084	5184	NA
Netherlands	NL	33	33	33	62
Norway	NO	127	159	522	564
Poland	PL	466	466	466	904
Portugal	PT	262	868	1040	6680

Romania	RO	1177	1318	1937	4112
Serbia	RS	1271	10254	10986	23675
Slovak Republic	SK	482.5	495	497	1803
Slovenia	SI	342	436	436	1762
Spain	ES	60	116.5	157	1179
Sweden	SE	245	245	245	343
Switzerland	CH	44.3	50	50	289
Turkey	TR	511.5	2393	5987	15194
Russian Fed.	RU	909	2204	2376	26826
Ukraine	UA	1458.5	3528	6062	NA
United Kingdom	GB	0	0	0	2715

Table A2.3. Further notes for application at NUTS0 level

NUTS0	Based on National stats	Disconnected	Connected Not treated	Primary treatment	Secondary treatment
IM	GB	0	0	0	2715
JE					
GG					
AD	ES	60	116.5	57	1179
LI	AT	52.86	52.86	52.86	63.87
SM	IT	136.7	1004	1118	2029

Annex 3. Inconsistencies detected in Waterbase-UWWTD v6 and rules for addressing them

Revision of the database was based on Amparore (2012) to address missing data and inconsistent PE transfers across tables. The main aim was to track the fate of all waste load generated from agglomerations, so priority was given to this information over other.

The tables that were revised were:

T_agglomerations: agglomerations and generated loads
T_uwwts: treatment plants info
T_uwwtsagglo: links between agglomerates and uwwts
T_dischargepoints: uwwts discharge points (dcp)
T_emissionloads: UWWTP loads in and out for some UWWTPs

The relationships in transfers from agglomerations to UWWTPS can vary from 1:1 to M:N. These transfers are specified in T_uwwtsagglo. Transfers from UWWTPs to DCPs can vary from 1:1 to 1:N (Fig. A2.1). Checks concerned patial coordinates of the items, and consistencies between transfers. We refer to coding as specified in the original database. The addition of "_EST" to coding indicates the entity as revised after applying the rule. Here below we specify how tables were checked and what rules were adopted. NA means missing information. <> means different from

Table T_agglomerations. The main check was that fractions of generated load (aggGenerated) that were collected (AggC1), transferred to IAS (aggC2), or not connected/not treated (aggPWT) would sum to 100:

Table A3.1. Rules for T_agglomeration

Inconsistency	**Rule**
Missing / Wrong spatial coordinate	a) Removed if aggGenerated< 2000PE b) Corrected coordinates based on Name
aggC2 is NA & aggC1+aggPWT=100	aggC2=0
aggC1+aggC2+aggPWT= 0|NA	aggC1, aggC2, and aggPWT = average of that member state with records; in the case of HR no record was reported, therefore SI values were applied
aggC1+aggC2+aggPWT <>100 & aggPWT =0	aggC2 = 100- aggC1
aggC1+aggC2+aggPWT <>100 & aggPWT > 0	aggPWT= 100 – (aggC1+aggC2)
aggC1+aggC2+aggPWT=100, but aggC1 wrong	aggC1=100, aggPWT=0
aggGenerated = 0|NA	no correction

aggGenerated=0, but 1:1 relation with uwwtps	aggGenerated inverted from load_in of uwwtps

Table T_uwwtpAgglo. Check 1: the sum of load entering the UWWTP (aucPerEnter) should equal the sum of transfers from agglomerations (Sum aggC1), allowing for a +/-3% error. Check 2: the sum of AucP2T (percentage transfer through transport) should be less or equal to the sum of aggC2.

Table A3.2. Rules for T_uwwtpagglo

Inconsistency	**Rule**
Agglomerations does not appear in table, but aggGenerated>0 & aggC1_EST>0 & spatial coordinates are valid	Added link to closest active uwwtp
Sum(aucPercEnter) =0|NA & aggC1_EST > 0	1:1 cases: aucPE_EST=aggC1_EST 1:N cases: aucPE_EST=aggC1_EST/n_uwwtps or share that is not transferred already to other UWWTPs
Sum(aucPercEnter) =0|NA & aggC1_EST = 0	aucPE_EST=aggC1_EST=0
Sum(aucPercEnter)> 1.03* aggC1_EST & aggC1_EST = 0	Corrected aggC1_EST and aggC2_EST in T_agglomerations
(Sum(aucPercEnter) > 1.03* aggC1_EST | Sum(aucPercEnter)< 0.97* aggC1_EST) & aggC1_EST > 0	aucPE_EST=aggC1_EST*aucPercEnt/sum(aucPercEnt) (corrected proportionally)
Sum(aucPC2T) = NA	AucPC2T_EST=0
Sum(aucPC2T)> 1.03*aggC2_EST	aucPC2T_EST=aggC2_EST*aucPC2T/sum(aucPC2T) (corrected proportionally)

After correcting for load transfers, UWWTPS incoming loads slightly changed (Fig A2.2)

Figure A3.1. The relationships of PE transfers portrayed in the database (from Amparore, 2012).

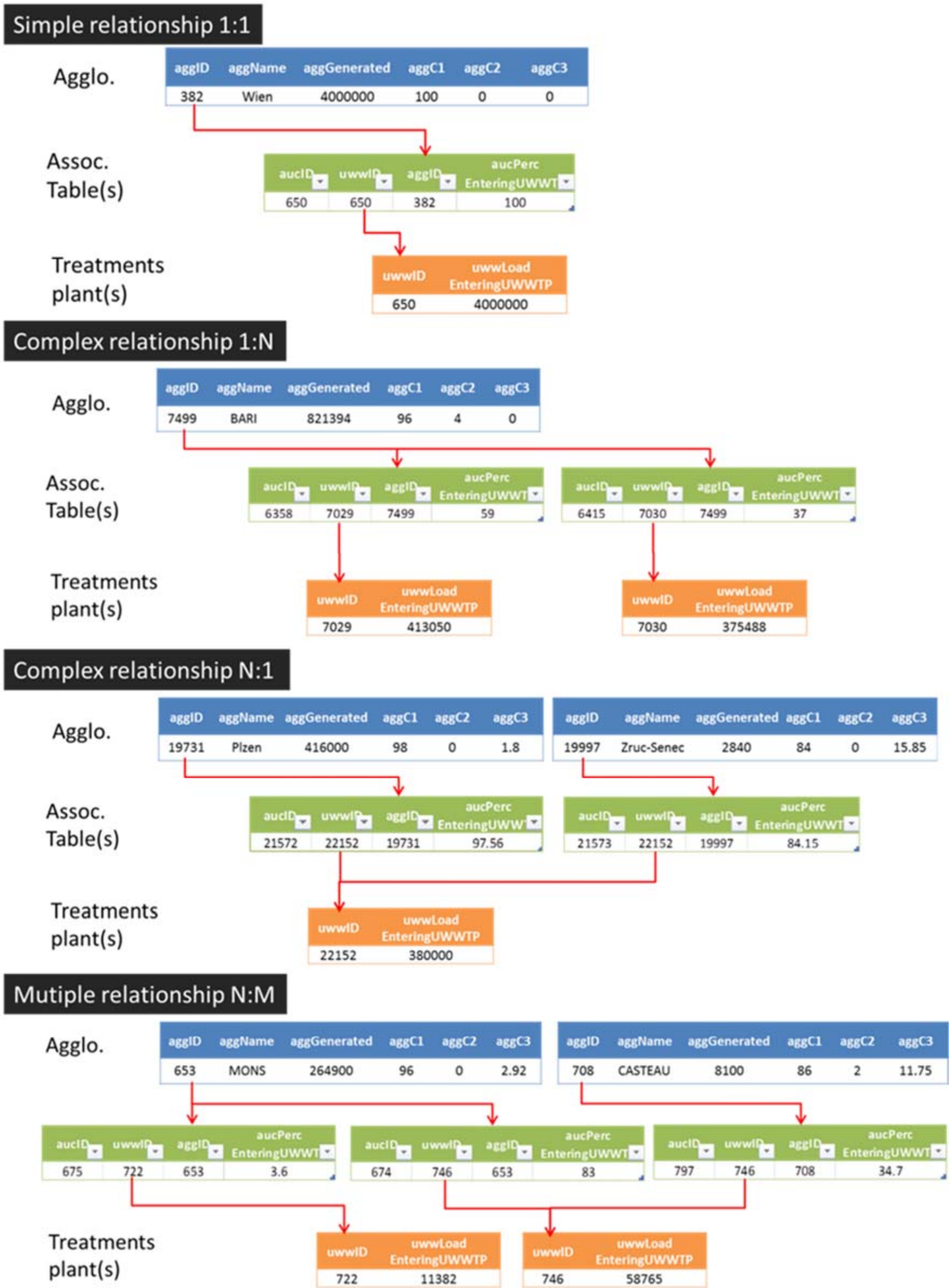


Table T_UWWTP. Check 1: entry is not a duplicate and has useful links

Table A3.3. Rules for T_UWWTPs .

Inconsistency	Rule
Missing / Wrong spatial coordinate	a) Derived from Agglo if link exists b) Corrected from UWWTPs Name c) Discarded if load = 0
DCPs is more than 50 km from UWWTPs	UWWTPs moved to DCPs or viceversa based on UWWTPs/DCPs/AGGLOs names
Duplicated entries	Removed UWWTPs with uwwCode appearing more than once
UWWTPs does not appear in T_uwwtagglo	Removed if a) history/comments indicates it is closed b) has no coordinates and no load, nor information about agglomeration name
UWWTPS does not appear in T_uwwtagglo but table reports agglomeration code	link added in T_uwwtagglo; link transfers sets respceting agglomeration aggC1_EST and aggC2_EST or entering load when declared

Check 2: the load entering the UWWTP is consistent with load transferred to it (allowing for a +/- 10% difference). Two ratios are considered:

$$A = \sum_{1}^{t} AucPercEnteringUWWTP\ /aggC1\_EST$$

$$R_{enter}^{trans} = \frac{\sum_{1}^{t}[aggGenerated\ *\ (aucPercEnteringUWWTP\ +\ aucPercC2T)/100]}{uwwLoadenteringUWWTP}$$

Table A3.4. Rules for T_UWWTPs but Load_in (load entering the UWWTp) is 0 or NA

Inconsistency	Rule
Load_in=0|NA but load_trsf=0 and A~1	Load_in = load_trsf = 0
Load_in=0|NA but A<>1	Correct aucPT_EST; load_in = load_trsf
Load_in > 0 but A<>1	UWWTPS is not linked to an existing agglomeration: accept as is

Table A3.5. Rules for T_UWWTPs when load entering does not correspond to load transfers (R_trsf<>1)

Inconsistency	Rule
R_trsf~1 but A <>1; Sum(aucPT_EST) = NaN	auc_PTEST corrected; load_in= new load_trsf
R_trsf<>1 but A~1	auc_PTEST corrected; Load_in = new load_trsf
R_trsf<>1 & A<>1	auc_PTEST corrected; Load_in = new load_trsf

Table A3.6. Setting of treatment level to T_UWWTPs

Inconsistency	Rule
P_removal =1	Treatment level = 4 (P_removal)
Any treatment except primary or secondary =1	tertiary
Secondary treatment = 1 but no other execpt primary	secondary
No or only primary treatment = 1	Primary

T_DischargePoints. Most checks were based on spatial location of DCPs, and links between UWWTPS and DCPs

Table A3.7. Rules for T_DischargePoints

Inconsistency	Rule
Missing / Wrong spatial coordinate	a) Derived from UWWTPs if link exists b) Inverted/Corrected based on UWWTPs/DCPs/AGGLOs names c) Discarded if State = 0
Duplicated entries	Removed DCPs with uwwCode appearing more than once
UWWTP has no DCP associated	If Load_EST>0 and UWWTP has coordinates, discharge emitted at UWWTP coordinate

DCP is more than 50 km from UWWTP	DCP moved at UWWTP coordinates or viceversa based on UWWTPs/DCPs/AGGLOs names

T_UWWTPs_emission_load. In a minority of cases, UWWTP loads entering and exiting the UWWTP were reported; these data was used when found consistent. The main checks were that (i) load exiting was lower than load entering, and that (ii) loads entering the UWWTPS were not too large compared to estimates of loads based on entering PE, as this pointed to likely errors in reporting units of measures.

Table A3.8. Rules for UWWTPs_emission_load

Inconsistency	**Rule**
BOD_, TN_, TP_ out = 0	Data not used
BOD_, TN_, TP_ out > BOD_, TN_, TP_ in	
BOD_out > 0.2 PE_in	
TN_OUT or TP_out > 0.01 PE_in	
UWWTPS in PL	Data was not used. Incoming and outgoing loads were not consistent with treatment level or previous declarations in v5. Inconsistencies could be in UWWTP treatment level or in reported loads, but they were considered unreliable

Annex 4. Variation of PE/population rate versus fraction of rural population or income

Figure A4.1. PE/population rate against fraction of rural population for the 15 countries that had <2% of disconnected population selected for the relationship PE/inhabitants. Fraction of rural population was taken from GHS2015 (CIESIN). No significant linear trend was detected.

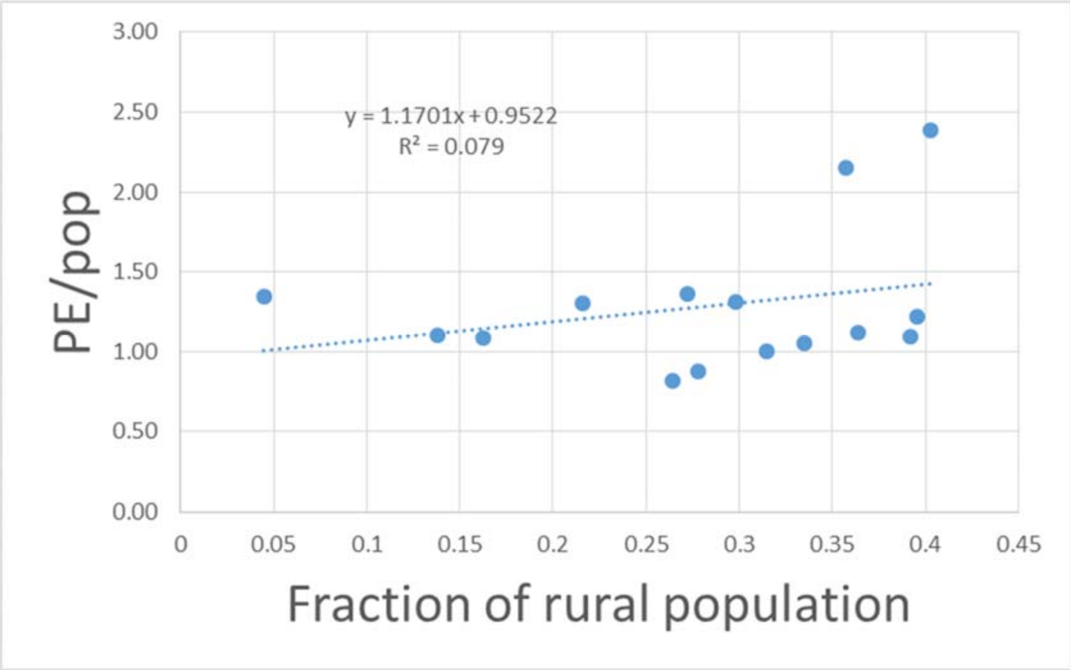
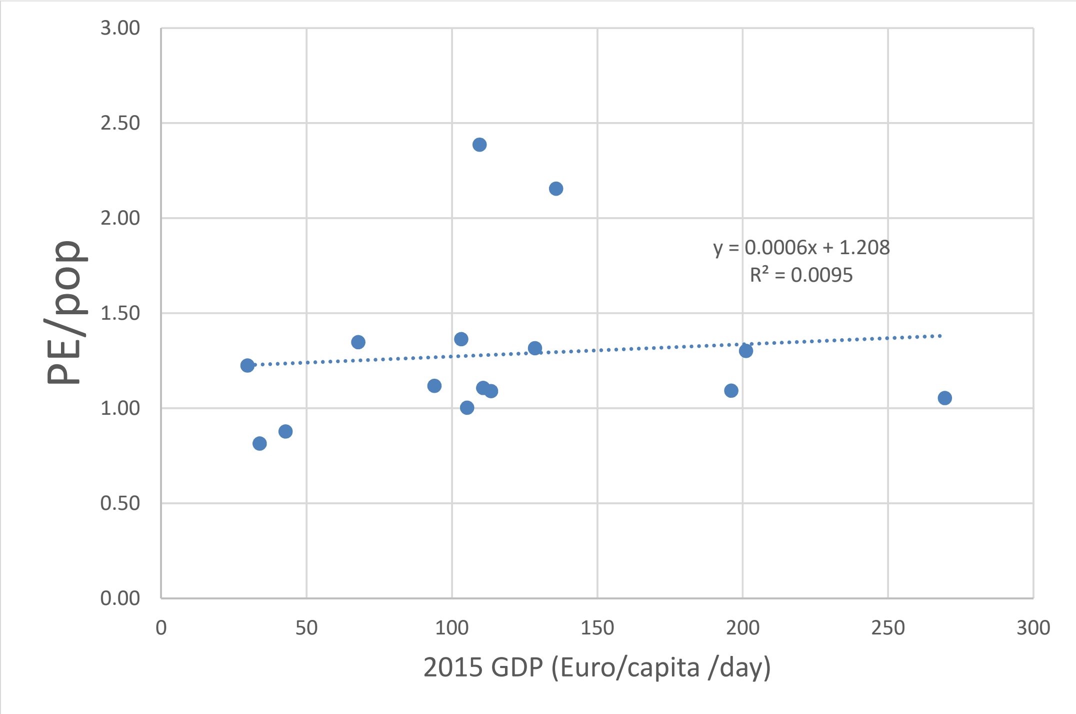


Figure A4.2. PE/population rate against country Gross Domestic Product (GDP/capita/day) for the 15 countries that had <2% of disconnected population selected for the relationship PE/inhabitants. GDP of 2015 was taken from Eurostat (2018). No significant linear trend was detected.



Annex 5. Population (inhabitants) estimated to belong to small agglomerations (<2000PE; Pop_RES) and attributed to Scattered Dwellings (Pop_RES_SD) or connected and not treated (Pop_RES_0).

Table A5.1 Country inhabitants that were estimated population reported in the UWWTD database (PRE), GHS2015 population (TotPop), and population (inhabitants) estimated to be unreported in UWWTD database because belonging to small agglomerations (<2000 PE, Pop_RES), and attributed to scattered dwellings (Pop_RES_SD) or connected not treated (Pop_RES_0) population.

Country	ISO 3166.1	PRE	TotPop	Pop_RES	Pop_RES_SD	Pop_RES_0
Austria	AT	16,577,241	8,547,384	0	0	0
Belgium	BE	7,555,202	11,202,697	1,808,272	983,945	824,327
Bulgaria	BG	6,599,693	7,172,845	573,213	573,213	0
Croazia	HR	4,090,380	4,110,381	20,000	20,000	0
Switzerland	CH	8,842,281	8,359,978	0	0	0
Cyprus	CY	808,943	1,134,834	325,890	325,890	0
Czech Republic	CZ	6,347,369	10,529,736	2,024,167	1,577,864	446,303
Denmark	DK	9,425,646	5,381,703	0	0	0
Estonia	EE	1,334,601	1,274,668	0	0	0
Finland	FI	4,394,390	5,392,738	928,022	928,022	0
France	FR	58,008,085	63,889,494	5,881,400	5,881,400	0
Germany	DE	89,616,521	80,900,286	0	0	0
Greece	GR	9,587,153	10,403,649	715,533	714,911	622
Hungary	HU	9,692,574	9,944,182	251,607	251,607	0
Ireland	IE	4,380,098	4,529,272	149,175	149,175	0
Italy	IT	63,397,015	58,129,872	0	0	0
Latvia	LV	1,293,424	1,954,774	564,597	559,156	5,441
Lithuania	LT	2,166,683	2,860,706	694,023	694,023	0
Luxembourg	LU	455,761	532,205	10,602	10,267	334
Malta	MT	417,074	380,959	0	0	0
Netherlands	NL	14,580,946	16,463,427	97,992	95,803	2,189
Norway	NO	4,215,421	4,747,658	532,236	532,236	0
Poland	PL	31,205,754	38,470,776	7,265,015	7,265,015	0
Portugal	PT	9,931,376	10,174,193	242,816	242,816	0
Romania	RO	18,995,344	19,604,258	608,911	608,911	0
Slovak Republic	SK	3,786,211	5,466,258	1,680,047	1,680,047	0
Slovenia	SI	1,205,060	2,076,848	871,788	775,267	96,521
Spain	ES	52,207,556	44,296,741	0	0	0

Sweden	SE	10,178,264	9,519,529	0	0	0
United Kingdom	GB	57,549,550	63,998,857	1220	869	351

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doi:10.2760/08152

ISBN 978-92-79-97297-3