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Nutrient recycling potential in the Baltic Sea Region

Sari Luostarinen (ed.)

Interreg
Baltic Sea Region



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Foreword

CiNURGi (Circular Nutrients for a Sustainable Baltic Sea Region) is an Interreg Baltic Sea Region Core Project accelerating the circular economy for nutrients across the region. By strengthening infrastructure, technology, and policy, the project advances recovery and safe return of nutrients from agricultural, municipal, and industrial streams. CiNURGi is aligned with the HELCOM Baltic Sea Regional Nutrient Recycling Strategy, the EU Circular Economy Action Plan under the European Green Deal, and the Farm to Fork Strategy's Integrated Nutrient Management Action Plan. The project runs from November 2023 to October 2026.

This report corresponds to Work Package 1, Activity 1, which maps nutrient-rich biomasses and their current treatment in the Baltic Sea Region. It establishes a comparable baseline for the status of nutrient recycling in the region's EU Member States, providing a clear starting point for targeted measures and enabling cross-border learning where countries are at different stages.

We acknowledge the contribution of our consortium, 24 partners and 13 associated organizations, from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden. Their commitment and expertise are essential to the project's progress.

For more information about CiNURGi and its activities, please visit our project homepage: <https://interreg-baltic.eu/project/cinurgi/>

Version 1.0 — 22 September 2025

Erik Sindhøj & Cheryl Cordeiro, CiNURGi Project Coordinators
RISE – Research Institutes of Sweden

This #MadeWithInterreg project helps drive the transition to a green and resilient Baltic Sea region and is part of the EU-funded Interreg Baltic Sea Region (BSR) core project #C049, titled CiNURGi, under the 2021-2027 PROGRAMME, Priority 3: Climate-Neutral Societies, Objective 3.1: Circular Economy.

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CIRCULAR ECONOMY

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Abstract

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This report contains information on the nutrient recycling potential in the Baltic Sea Region. The information was collected with two different methods: a Eurostat-based method for all countries and national data collection separately for each country. The recyclable biomasses considered were livestock manure, sewage sludge, municipal biowaste and different industrial side streams.

The Eurostat-based data is uniform for all countries and gives indication of nutrient recycling potential in the Baltic Sea Region on NUTS2 level of spatial distribution. However, it fails to consider national differences in the nutrient contents of the recyclable biomasses and the NUTS2 level is too coarse to identify regions of nutrient surplus or deficit in many of the countries.

National data collection can provide more detailed spatial resolution for at least some of the recyclable biomasses and offer nationally more accurate data on the nutrient contents. However, the data is scattered into various sources and includes gaps and uncertainties which should be improved by developing the national data collections.

To monitor the nutrient recycling potential and the need for nutrients especially in agricultural production, the regions of surplus and deficit should be nationally estimated by comparing the amount of nutrients to be recycled and the fertilization need within each country and region. This report offers an example of such a calculation for Finland.

Information on the nutrient recycling potential is a basis for planning, promoting and implementing nutrient recycling measures. Thus, it should be organized country-specifically by designating responsible organization(s), resourcing them sufficiently for a regular updating of the data, and including an analysis of the current status of the use of the recyclable biomasses. The monitored information highlights the progress of nutrient recycling and identifies development needs. Methodology for the monitoring process should still be developed further within the scientific community.

Keywords: Nutrient recycling, Circular economy, Nitrogen, Phosphorus, Fertilizing product.

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1. Introduction

Sari Luostarinen, Natural Resources Institute Finland (Luke)

Circular economy is increasingly promoted as a vital part of sustainable and resource-efficient society. It aims at enhancing resource management by maximising the reuse of all materials and minimising waste and emissions into the environment. Circular economy can be seen as a model for production and consumption that extends the life cycle of materials by recreating their value repeatedly.

Nutrient recycling is an important part of circular economy. Nutrients are needed in many activities, but especially in food production where the crops grown require them to ensure high yields with good quality. Originally, livestock manure was the main fertilizing product used in agriculture. While it is still of importance, during the 1900s, the use of mineral fertilisers increased and especially after the World War II, their use soared into new levels with the aim of increasing crop yields. Since then, restrictions to fertilisation were gradually introduced as their overuse was causing notable environmental problems, especially as eutrophication of surface waters and/or deterioration of ground water quality. In the EU, the use of mineral fertilizers has decreased over the years being 8.34 million tons of nitrogen and 0.92 million tons of phosphorus in 2023 (Eurostat 2025). On top of this different fertilizing products of organic origin, livestock manure, biological nitrogen fixation and green manuring are used as sources of nutrients.

Nutrient loading into waters and subsequent eutrophication is an important issue in the Baltic Sea Region. The Baltic Sea is sensitive to pollution due to its unique features as a shallow, inland sea and the pressure of eutrophication is still significant despite decades of measures to reduce nutrient loading (see e.g. HELCOM 2023).

The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM) – is an intergovernmental organisation and a regional sea convention in the Baltic Sea area. One of the major pressures to the Baltic Sea is diffuse pollution from agriculture with the nutrient loading causing eutrophication of the sea. Hence, the Contracting Parties of HELCOM (all coastal countries and the European Commission) have adopted a strategic programme of measures and actions for achieving good environmental status of the sea – Baltic Sea Action Plan (BSAP) last updated in 2021 (HELCOM 2021a). The programme includes several measures to reduce agricultural nutrient loading and – as a new topic – to promote nutrient recycling in the region. Baltic Sea Regional Nutrient Recycling Strategy (HELCOM 2021b) contains more detailed objectives for nutrient recycling and examples of measures to reach them.

To create effective strategies to promote and to practically implement nutrient recycling the baseline needs to be known. This means estimation of the nutrient recycling potential nationally and transnationally. Firstly, the major raw materials suitable for nutrient recycling – recyclable biomasses - within a region or a country need to be identified. Then, the amount of nutrients, the main nutrients of nitrogen and phosphorus at minimum, need to be estimated. The geographical distribution of the biomasses needs to be studied to identify potential hot spots, i.e. areas in which recyclable nutrients are available in abundance. This will facilitate planning of recycling measures required to make use of the nutrients effectively. More

detailed hot spot identification and planning of measures can further be done if the availability of recyclable nutrients can be connected to the regional need of nutrients for fertilization. This requires a vast amount of data also on the local agricultural production and soil properties on top of data on the recyclable biomasses.

The main aim of this report is to introduce the basic logic of collecting data on recyclable biomasses nationally and regionally as such data is often difficult to obtain and the level of detail varies significantly. The results can be used as an indication of the nutrient recycling potential in the Baltic Sea Region and offer a starting point to monitoring the degree to which the potential is being exploited and to plan promotion of more effective recycling. The results also respond to the HELCOM BSAP Actions under theme 'Nutrient recycling' (E30-E36) and the objectives of the Baltic Sea Regional Nutrient Recycling Strategy.

In this report, the potential of nutrient recycling in the Baltic Sea Region (excluding Russia) is estimated with two approaches. The first is an attempt to base the data collection mainly on Eurostat (Luostarinen et al. 2021) to get comparable information collected with the same method for all countries. The second approach focuses on using national data sources which may be more specific than what Eurostat offers and difficult to reach due to language barriers. The data on recyclable biomasses presented in the report are also available as a database in the following links:

- Database including biomass data collected from **national** data sources: <https://zenodo.org/records/17287851>
- Database containing biomass data collected based on **Eurostat** statistics: <https://zenodo.org/records/17288096>

References

- Eurostat 2025. Consumption of inorganic fertilizers. https://doi.org/10.2908/AEI_FM_USEFERT
- HELCOM 2021a. Baltic Sea Action Plan. 2021 update. Baltic Marine Environment Protection Commission. <https://helcom.fi/wp-content/uploads/2021/10/Baltic-Sea-Action-Plan-2021-update.pdf>
- HELCOM 2021b. Baltic Sea Regional Nutrient Recycling Strategy. Baltic Marine Environment Protection Commission. <https://helcom.fi/wp-content/uploads/2021/10/Baltic-Sea-Regional-Nutrient-Recycling-Strategy.pdf>
- HELCOM 2023. State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194. https://helcom.fi/post_type_publ/holas3_sobs
- Luostarinen, S. Lehtonen, E., Skyttä, A., Seppänen, A.-M., Tampio, E. 2021. Dataset of regional NRSS available for producing BBFs in the EU. Deliverable 1.1-D5_WP1. Project LEX4BIO. https://lex4bio.eu/wp-content/uploads/2022/09/LEX4BIO_D1.1_WP1-1.pdf

2. Nutrient recycling potential in the BSR – Eurostat-based data

Sari Luostarinen, Eeva Lehtonen, Elina Tampio & Johanna Laakso, Natural Resources Institute Finland (Luke)

There are no international rules or instructions for how to estimate the nutrient recycling potential available in a given region. Therefore, all potentially useful datasets available in the literature are collected in various ways, from various sources and at various times. To collect at least moderately comparable data on nutrient recycling potential, a general method for all regions, whether e.g. transnational regions consisting of two or more countries, countries or smaller regions within a country, is needed.

Attempts at collecting such generally comparable data have been made for some recyclable materials and the results are available in literature. For example, the amount of livestock manure has been estimated previously by Foged et al. (2009) and Köninger et al. (2019) for certain livestock categories using different data sources, but methods for estimating the manure production and its nutrient content of all relevant livestock categories, i.e. cattle, pigs, poultry, horses, sheep, goats, and fur animals, are to our knowledge not available.

Thus, during the EU Horizon-funded project LEX4BIO, we created a very basic method for general estimation of nutrient recycling potential in the EU (Luostarinen et al. 2021). Then method includes a solution for how to estimate the nutrient content in livestock manure, sewage sludge, municipal biowaste and some industrial side streams (animal by-products and grape pomace relevant in this report). It is noted that there may be other recyclable biomasses also available in the Baltic Sea region, but they may either be more relevant in some of the countries than in others, data on their annual amount may not be linked to Eurostat data, and/or it is difficult to know what share of all production could be considered a side stream. The latter refers especially to the side streams on plant production in agriculture though there may be significant amounts of nutrients already being circulated as e.g. feedstock to biogas plants as leftover silage or straw. Also, it can be argued that the original wastewater should be considered as a side stream and its nutrient prior to wastewater treatment should be included in the potential. However, in this report, only the nutrients bound to sewage sludge during the treatment in current treatment plants is included. In the future, the infrastructure related to wastewater may change, but this is not scenarized here.

In this report, the Eurostat-based method is updated and used to calculate a general estimate of nutrient recycling potential in the Baltic Sea Region. As the method is based on Eurostat statistics, the nutrient recycling potential of Russia is excluded.

2.1. Materials and methods

Eurostat-based method starts from the target of using as much Eurostat statistics as possible as the background data for calculating annual nitrogen and phosphorus content in recyclable biomasses. The countries included in the calculation are thus the EU member states of the Baltic Sea Region.

The biomasses chosen for calculation are the ones deemed the most significant in the area chosen, the EU-27 originally (Luostarinen et al. 2021) and the Baltic Sea Region in this report. The biomasses included here are livestock manure, sewage sludge, municipal biowaste and two industrial side streams, i.e. animal by-products and grape pomace.

Not all required information is available in the Eurostat data. Therefore, especially the nutrient contents of the recyclable biomasses are derived from literature with the attempt to use a general coefficient not considering potential national differences in the characteristics of the biomasses.

The spatial distribution of the nutrients in the chosen biomasses included is considered in the highest resolution possible using the Eurostat data. This means that the aim is to use the most detailed NUTS-regions possible for each biomass. The NUTS (Nomenclature of Territorial Units for Statistics) regions are a hierarchical system used by the EU for statistical purposes. They are divided into three main levels:

- NUTS 1: These are the major socio-economic regions. Examples include large areas like the entire country of Sweden or regions like Southern Germany.
- NUTS 2: These are basic regions for the application of regional policies. They are smaller than NUTS 1 regions and often correspond to provinces or states. For instance, Uppsala County in Sweden is a NUTS 2 region.
- NUTS 3: These are small regions for specific diagnoses. They are the smallest units in the NUTS hierarchy and can correspond to individual municipalities or districts.

For livestock manure, NUTS1 is used for Germany and NUTS2 for the other Baltic Sea countries. For the municipal sewage sludge and biowaste, the data is based on population and thus available at NUTS2 level. Animal by-products and grape pomace are calculated on national level.

Data for mapping was retrieved from Eurostat database by R eurostat package (Lahti et al. 2017, 2023).

A more detailed description of the Eurostat-based method is available in Appendix.

2.2. Results for the BSR

The amount of nutrients in livestock manure (including cattle, pigs and poultry) is dependent on number of animals reared in a country. The amounts of nutrients in sewage sludge and municipal biowaste are dependent on the population. The amount of nutrients in animal-by-products follow the number of animals to be slaughtered for food, and in the only other industrial by-products included here, grape pomace, the amount of wine produced in a country. The total annual amount of nitrogen and phosphorus produced in the Baltic Sea Region thus becomes 3.096 million tons of nitrogen and 0.671 million tons of phosphorus (Table) 1. The spatial distribution of the recyclable nutrients are presented in Figures 1-4.

Table 1. Nutrient recycling potential in the Baltic Sea Region including the nutrients (t/a) in livestock manure, sewage sludge, municipal solid waste, animal by-products and grape pomace (only in Germany).

Country	Livestock manure		Sewage sludge		Municipal biowaste		Animal by-products		Grape pomace	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Finland	78 496	13 921	6 179	4 173	3 170	411	4 207	937	-	-
Estonia	21 080	3 369	838	566	162	21	474	109	-	-
Latvia	31 398	4 783	785	530	320	42	1 100	245	-	-
Lithuania	60 350	9 936	1 863	1 258	740	96	2 286	510	-	-
Poland	903 846	174 444	22 355	15 097	7 343	953	49 427	10 753	-	-
Denmark	237 475	43 280	5 429	3 666	9 922	1 287	13 916	3 120	-	-
Germany	1 273 791	224 478	65 785	44 426	78 032	10 123	59 469	13 338	2 640	113
Sweden	133 450	23 663	7 846	5 299	5 606	727	6 243	1 397	-	-
Total for the BSR	2 739 886	497 874	111 080	75 015	105 296	13 660	137 121	30 409	2 640	113

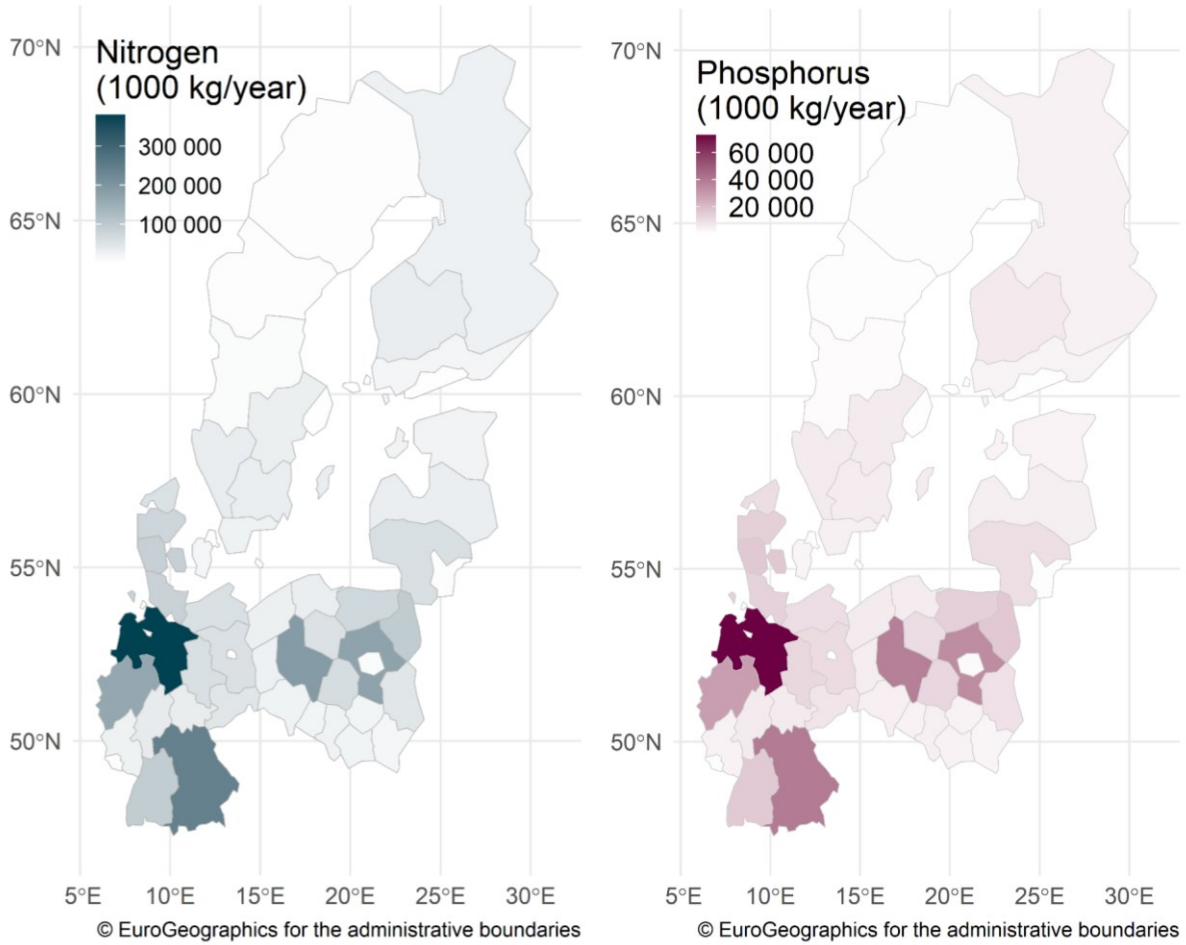


Figure 1. Spatial distribution of nitrogen (left) and phosphorus (right) in **livestock manure** in the Baltic Sea Region (NUTS2-level for all other countries except NUTS1 for Germany).

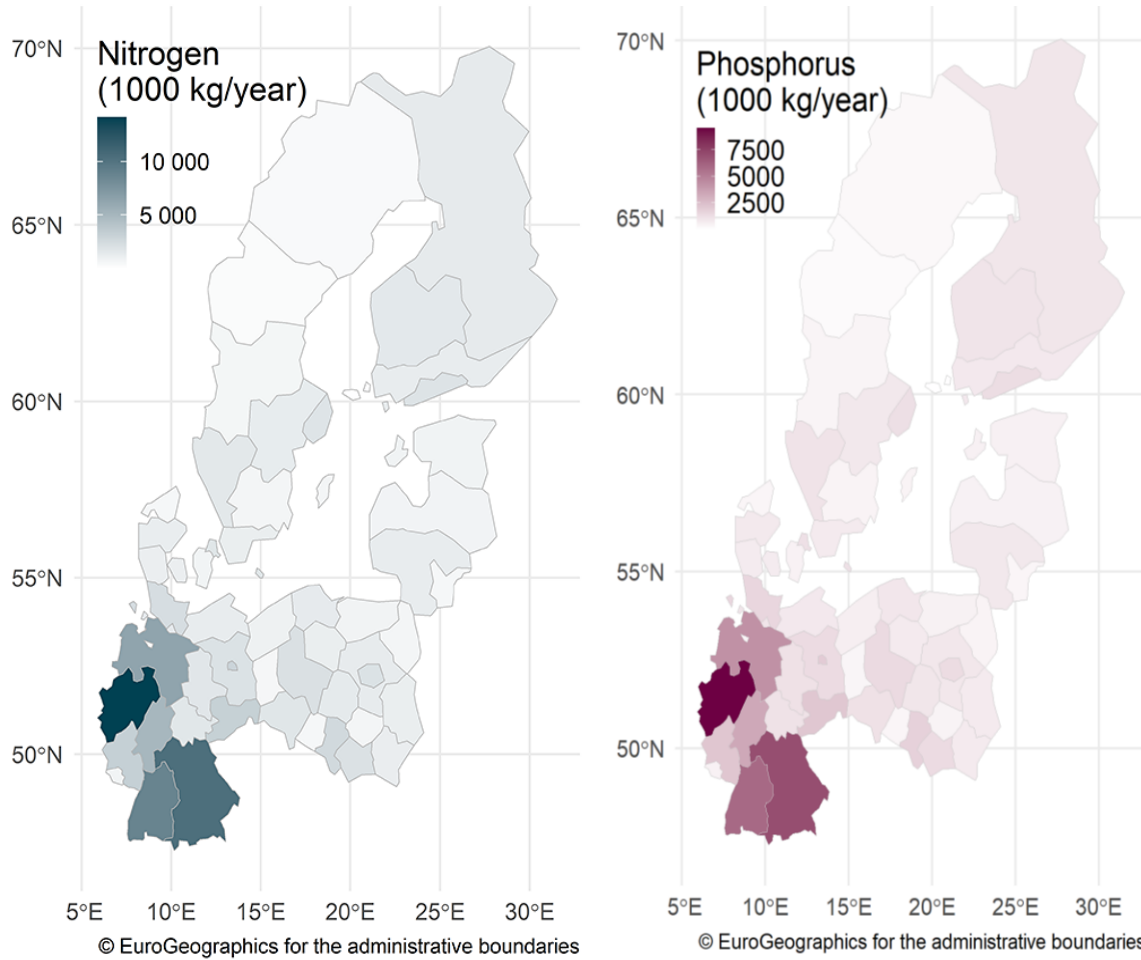


Figure 2. Spatial distribution of nitrogen (left) and phosphorus (right) in **sewage sludge** in the Baltic Sea Region on NUTS2-level.

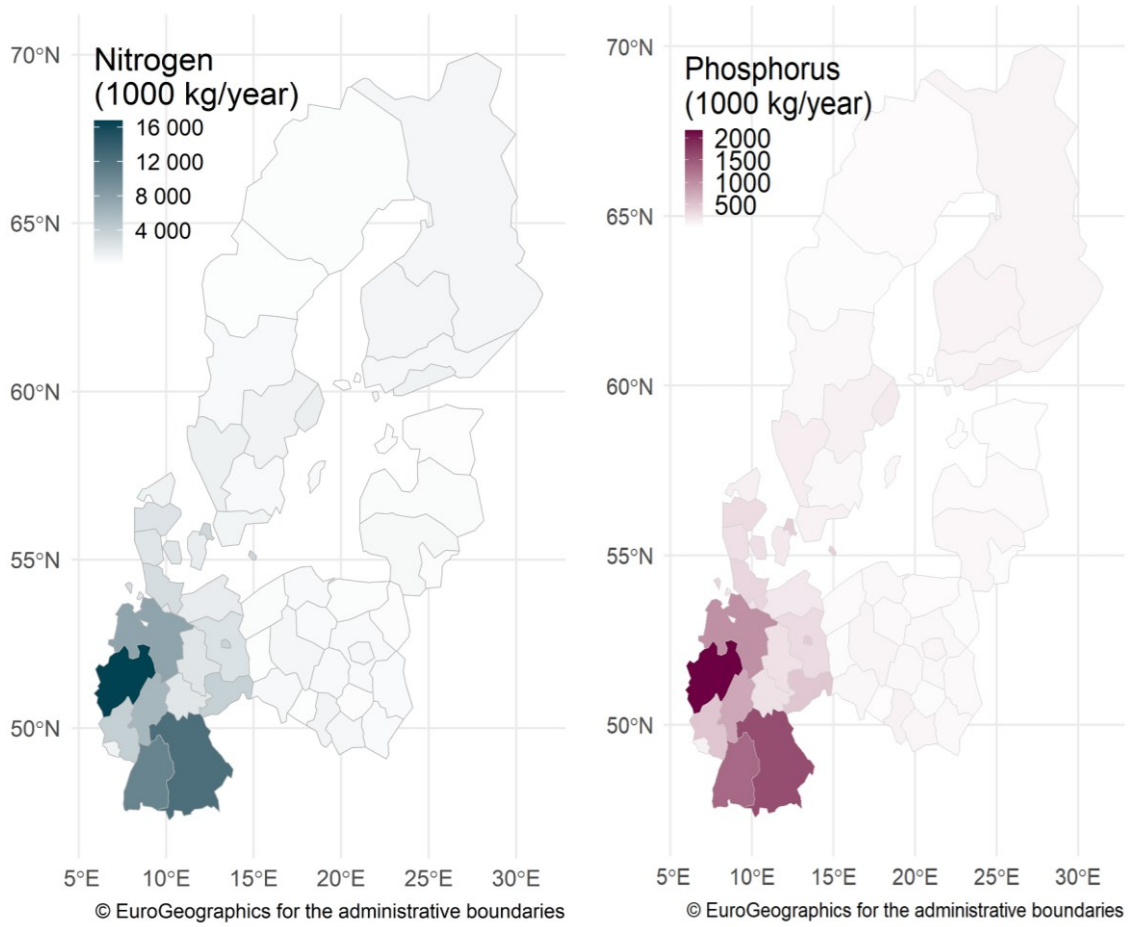


Figure 3. Spatial distribution of nitrogen (left) and phosphorus (right) in **municipal biowaste** in the Baltic Sea Region on NUTS2-level.

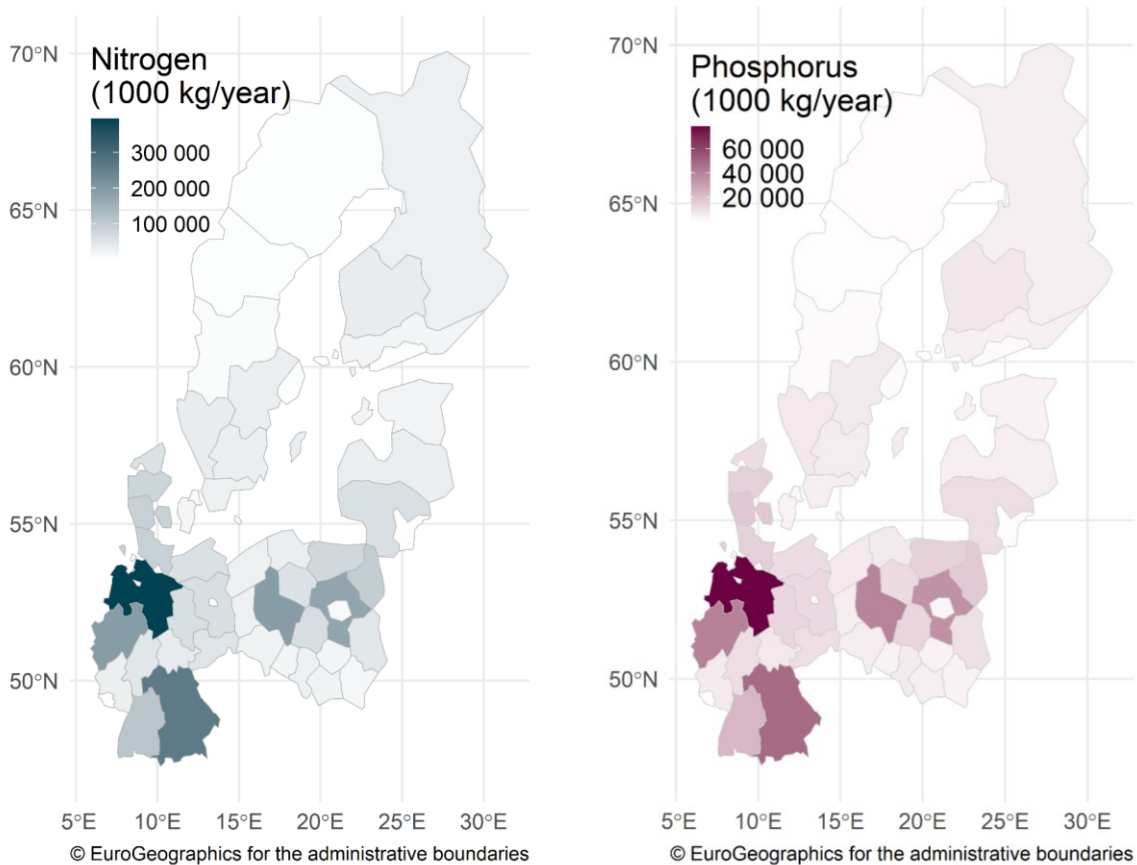


Figure 4. Nitrogen (left) and phosphorus (right) recycling potential in the Baltic Sea Region altogether for **livestock manure, municipal biowaste and sewage sludge**.

The amount of nutrients in livestock manure surpasses that of all other major wastes and side streams produced, containing 2.7 million tons of nitrogen and 0.5 million tons of phosphorus altogether for the Baltic Sea Region (Table 1). It is also good to note that the calculation includes cattle, pigs, poultry, sheep and goats, while nutrients in horse and fur animal manure are excluded. The Eurostat database does not include all horses (only the ones on farms, not in private stables) and any of fur animals (which are reared in some BSR countries).

The amount of livestock manure also reflects the intensity of livestock production per country and their sub-regions, with less nutrients in countries with less animals (Figure 1). The division of manure data into NUTS2 regions (NUTS1 for Germany) does not reflect the regional intensity of the manure production similarly for all BSR countries. For Estonia, Latvia and Lithuania, the NUTS2-level still means the whole country, neglecting showing the regional variation within the countries altogether. For Finland, the NUTS2 regions are rather large and do not reflect the spatial distribution properly, either. For Sweden, Denmark and Poland, the regional concentration of livestock and thus manure production is better shown on NUTS2-level, while for Germany already NUTS1-level shows the distribution rather well.

The nutrient content used as excreted nitrogen and phosphorus offers a good indicative information on the amount of manure nutrients produced and allows to compare the countries with each other. However, it overestimates the amount of nitrogen eventually available for plants as it does not account for nitrogen losses during animal housing and manure storage. It also lacks information on manure types produced, which affects the actual mass of manure to be stored and spread. This information would also be important for planning measures to

enhance manure use via e.g. co-operation between farms and manure processing in different scales. Moreover, the excretion data used describes the German livestock production which may not reflect the livestock rearing and feeding in other countries.

The other significant biomasses for nutrient recycling are municipal biowaste, sewage sludge and animal by-products, though even after summing them up, the amount of nutrients to be recycled are less than those of manure, being in total 353 497 tons for nitrogen and 119 084 tons for phosphorus (Table 1). The spatial distribution of the municipal wastes (biowaste: Figure 2; sewage sludge: Figure 3) is dictated by the population density, thus both showing the highest amounts in areas of most population. The NUTS-division is similar as with livestock manure. To get a better insight into potential hot spots of significant amounts of nutrients, more detailed spatial resolution is needed than the data in Eurostat database allows.

When evaluating sewage sludge, it is important to recognize that the quantity of sludge and its nutrient content reflect only the residuals remaining after the treatment of raw sewage. Conventional wastewater treatment processes typically convert nitrogen compounds to nitrogen gas released into the atmosphere, limiting opportunities for its recovery. Notably, urine accounts for approximately 79% of the nitrogen load entering wastewater treatment plants (Martin et al. 2020). Therefore, the original potential for nitrogen recovery from human urine can be estimated using population density data and relevant coefficients (11.7 gN/capita/day, Martin et al. 2020). Across the EU member states of the BSR (population 149.2 million), the theoretical nitrogen recovery potential from urine exceeds 600 000 tonnes of nitrogen, which is nearly six times greater than the amount estimated to end up in raw sewage sludge (111 080 tN; see Table 1). This highlights the critical need for innovative nitrogen recovery solutions at wastewater treatment facilities, as well as the implementation of source-separation strategies for urine and faeces, where feasible.

It is also important to note that nutrient availability, as assessed using Eurostat-based data, does not necessarily reflect the actual geographic location of the nutrients. In the case of manure, the place of generation is typically accurate, since manure is rarely transported over long distances for processing. However, for municipal and industrial side streams and by-products, the estimated nutrient generation site may not correspond to where the population resides or where food processing occurs. These waste streams are often transported to treatment facilities, which may be located far from their point of origin, depending on local and regional processing capacity.

The use of literature coefficients for the nutrient content in municipal biowaste, sewage sludge and animal by-products allows for an indicative information on nutrients contained in these biomasses, but does not reflect potential variation between the BSR countries. The variation arises from the different diets and consumption habits, and, in the case of sewage sludge, wastewater processing technologies applied. While the amounts of biowaste and sewage sludge produced per capita in each country are national data, the result does reflect national conditions. With animal by-products, national variation could arise from the consumption habits and slaughtering practises applied. Despite the use of uniform coefficients, the national number of slaughtering animals was used to show national variation in nutrient amounts.

For other nutrient-rich industrial side streams than animal by-products, the Eurostat database does not give proper data. The many different side streams of e.g. food processing are not

available and thus the Eurostat-based method cannot offer data on the smaller potential biomasses for nutrient recycling. On national level, these should also be identified and quantified because they may locally be of significance. The same also applies to nutrient amounts, which are not available in the Eurostat. Therefore, it is strongly recommended to use national nutrient coefficients where available.

To compare the availability and need for nutrients within countries and their sub-regions, the amount of nutrients in the recyclable biomasses needs to be compared to the fertilization need. This can be done simply by comparing the nutrient amounts to utilized agricultural area (hectares) or in more detail by considering also the soil conditions, and the plants being produced and their fertilization need. This is discussed in more detail in chapter 4.

References

- Foged, H.L., Flotats, X., Bonmati Blasi, A., Palatsi, J., Magri, A., Schelde, K.M. 2011. Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 138 pp. <https://op.europa.eu/fi/publication-detail/-/publication/d629448f-d26a-4829-a220136aad51d1d9#>
- Köninger, J., Lugato, E., Panagos, P., Kochupillai, M., Orgiazzi, A., Briones, M.J.I. 2019. Manure management and soil biodiversity: Towards more sustainable food systems in the EU. *Agricultural Systems* 194(103215): 1–24. <https://doi.org/10.1016/j.agsy.2021.103251>
- Lahti L., Huovari J., Kainu M., and Biecek P. 2017. Retrieval and analysis of Eurostat open data with the eurostat package. *The R Journal* 9(1): 385–392. <https://doi.org/10.32614/RJ-2017-019>
- Lahti, L., Huovari J., Kainu M., Biecek P., Hernangomez D., Antal D., Kantanen P. 2023. eurostat: Tools for Eurostat Open Data [Computer software]. R package version 4.0.0. <https://github.com/rOpenGov/eurostat>
- Luostarinen, S. Lehtonen, E., Skyttä, A., Seppänen, A.-M., Tampio, E. 2021. Dataset of regional NRSS available for producing BBFs in the EU. Deliverable 1.1-D5_WP1. Project LEX4BIO. https://lex4bio.eu/wp-content/uploads/2022/09/LEX4BIO_D1.1_WP1-1.pdf
- Martin, T.M.P., Eculier, F., Levavasseur, F., Houot, S. 2020. Human urine-based fertilizers: A review. *Critical Reviews in Environmental Science and Technology* 52: 890–936. <https://doi.org/10.1080/10643389.2020.1838214>

3. Country-specific nutrient recycling potential – based on national data

Since the Eurostat-based method uses mainly general coefficients for nutrient contents in the different recyclable biomasses without consideration of potential national variation in them, the second approach for estimating nutrient recycling potential is based on national data. This data may include more detailed information on the biomasses related to their amount, characteristics and spatial distribution.

In this chapter, estimations of country-specific nutrient recycling potentials are presented using the national data available at the time of writing for the authors. It is possible that there are even more detailed data available still for some countries, but those data were not found during this project. The results presented here offer a starting point from which the data collection can be further developed. Results are presented for Finland, Estonia, Latvia, Lithuania, Poland, Germany and Sweden. Information on Denmark can be found in Foged (2024¹).

3.1. Finland

Sari Luostarinen, Eeva Lehtonen, Elina Tampio & Johanna Laakso, Natural Resources Institute Finland

Finland has been actively promoting nutrient recycling since the Finnish Government committed to making Finland an example region of nutrient recycling in the Baltic Sea Action Summit in 2010. A working group, led by then Prime Minister Matti Vanhanen, published a report "Finland for a model country of nutrient recycling" (MMM 2011), including a vision for 2020, description of the status then and suggestion for measures henceforth. Since then, the data on the Finnish nutrient recycling potential has been updated and the calculation method improved several times.

The potential for nutrient recycling is currently calculated by Natural Resources Institute Finland (Luke) approximately every three years. The information on recyclable biomasses is collected from various sources and the data is made available for national, regional (15 regions governed by Centres for Economic, Development, Transport and the Environment, ELY-Centres in short) and municipal level. In this report, the level of ELY-regions is used (Figure 5) and the results presented here have been calculated for the indicator for nutrient recycling in Finland during 2021-2022 (Luostarinen et al 2023). The next update of the data will be done in 2025.

¹ Foged, H. L. 2024. Potentials for higher recycling of nutrients in organic wastes from farming, industry and households - The current situation and scenarios for future development in Danish NUTS2 regions. Report. Organe Institute. <https://doi.org/10.13140/RG.2.2.28437.23520>



Figure 5. The Finnish regional ELY-Centres for which the nutrient recycling potential is calculated in this report: 1) Lapland, 2) North Ostrobothnia, 3) Kainuu, 4) Ostrobothnia, 5) South Ostrobothnia, 6) Central Finland, 7) North Savo, 8) North Karelia, 9) Satakunta, 10) Pirkanmaa, 11) Häme, 12) South Savo, 13) Southeast Finland, 14) Southwest Finland, 15) Uusimaa.

3.1.1. Materials and methods

The amount and properties of livestock manure are calculated using manure data per animal category from the Finnish Normative Manure System (Luostarinen et al. 2017a, 2017b). The system calculates manure using national excretion data for cattle, pigs, poultry, horses, sheep, goats and fur animals as the starting point (*manure ex animal*). It then uses the national information on average livestock housing systems (giving also the shares of different manure types produced per animal category in Finland), grazing periods and manure storage solutions used (Grönroos et al. 2017), producing manure data per animal category as manure directly from housing (*manure ex housing*) and manure after storage (*manure ex storage*). When calculating the potential for nutrient recycling *manure ex housing* is used due to this data describing the manure potentially used in manure processing the best (manure should be directed to processing as fresh as possible). The share of excreta left on pastures by the grazing animals (cattle, sheep, goats) is excluded from the manure data.

The manure data is then combined with livestock statistics including the information on livestock location. The number of cattle, pigs, poultry, sheep and goats is from the statistics of Finnish Food Authority (here for animals in 2020), the number of horses in 2018 from Hippos (Central Organisation for Trotting and Horse Breeding), and the number of fur animals in 2021 from Fifur (Finnish Fur Breeders' Association). The amount and properties of manure per animal are multiplied with the number of animals, thus receiving total amounts of manure and manure nutrients in Finland. As the information of the location of the animals is included into livestock statistics, different regional levels can be formed and their manure data calculated.

The amount and spatial distribution of sewage sludge is based on national population statistics (Statistics Finland 2020) and a coefficient per capita (66.8 g dry matter per capita per day) calculated from the total amount of sewage sludge in 2020 (Finnish Water Utilities Association 2021). The amount of sewage sludge is the amount of raw sludge in the wastewater treatment plant prior to any sludge handling. The dry matter content of the raw sludge is 3.2%. The nutrient content of this sludge is derived from a literature survey (Table 2; more detailed data available in Luostarinen et al. 2023).

Table 2. The properties of the recyclable biomasses from municipalities and industries (DM = dry matter).

	Dry matter (%)	Ntot (%DM)	Ptot (%DM)
Municipal biowaste	28	2.2	0.4
Sewage sludge	3.2	5.5	3.0
Side streams from industries			
Animal by-products	35	9.0	0.7
Sludges of animal origin	20	4.0	2.0
Fatty waste	40	0.3	0.2
Plant waste	27	2.0	0.2
Milk and dairy waste	6	5.0	1.0
Bakery waste	75	2.2	0.3
Beverage production waste	11	6.0	1.2

The amount of municipal biowaste per capita, meaning separately collected food waste from kitchens and canteens (including households and public places) and green waste from gardens and parks, is calculated from the waste statistics for the year 2020 (Official Statistics of Finland). The amount of such biowaste per capita was 89 kg per year in 2020. The nutrient content of the municipal biowaste is derived from a literature survey (Table 2; more detailed data available in Luostarinen et al. 2023).

The amount of nutrient-rich side streams from industry is based on data collected from the YLVA System used by the Finnish environmental administration (year 2020). The data includes information from business activities with an environmental permit, thus obliged to report the received and removed waste and side streams of their production as part of the annual reporting. The wastes and side streams are divided into different categories with LoW codes (List of Waste; previously European Waste Catalog EWC) from which the nutrient-rich, biodegradable biomasses can be differentiated. Based on the codes, seven waste categories for typical nutrient-rich side streams from Finnish food processing industry were identified (Table 2). The nutrient content of these categories is derived from a literature survey (Table 2; more detailed data available in Luostarinen et al. 2023).

3.1.2. Nutrient recycling potential in Finland

The nutrient recycling potential in Finland consists of 17.9 million tons of different recyclable biomasses containing 89 910 tons of nitrogen and 20 375 tons of phosphorus (Table 3). Livestock manure is the most important side stream to be recycled, making up 72% of the mass of all side streams, 81% of nitrogen and 74% of phosphorus (Figure 6). The second most important side stream from the viewpoint of nutrients is sewage sludge with 8.1% of nitrogen and 20% of phosphorus. The shares of the other side streams are smaller.

Table 3. The amount and nutrient content of different recyclable biomasses in Finland in 2020.

	Mass (t/a)	Ntot (t/a)	Ptot (t/a)
Livestock manure	12 858 573	72 475	15 092
Municipal biowaste	481 016	2 964	539
Sewage sludge	4 135 616	7 279	3 970
Animal by-products	243 628	6 451	686
Industrial side streams	151 113	740	88
Total	17 869 946	89 909	20 375

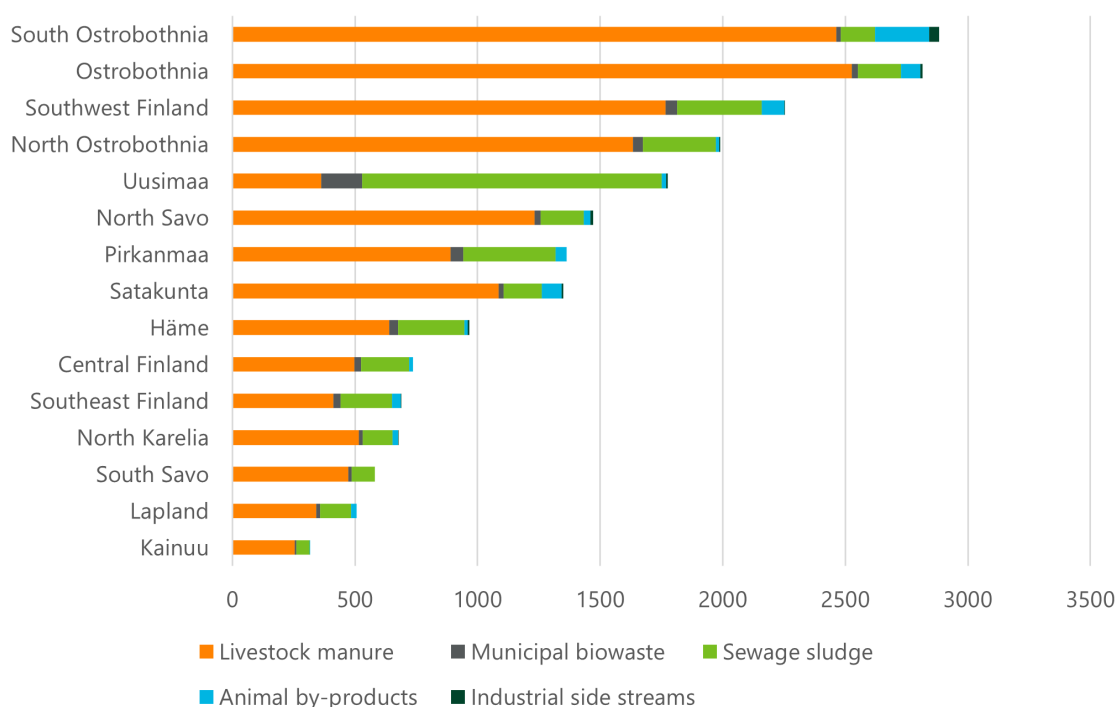


Figure 6. Phosphorus (t/a) in the different recyclable biomasses per ELY-Centre in Finland (2020).

Livestock manure

Livestock manure is the major recyclable biomass in all other ELY-regions except Uusimaa, which is the most densely built and inhabited region in Finland (Figure 6). Livestock production is especially concentrated along the western ELY-regions and North Savo, while the industrial side streams are produced more evenly across the country. A higher share is visible in South Ostrobothnia for animal by-products due to the major rendering plant being located there.

When looking more closely at livestock manure (Figure 7), most of it is cattle manure comprising 9.66 million tons (75% of all manure) and containing 50 106 tons of nitrogen (69% of all manure nitrogen) and 8 553 tons of phosphorus (57% of all manure phosphorus). The amount of pig manure is 2.10 million tons (16%) with 9 897 tons of nitrogen (14%) and 2 108 tons of phosphorus (14%). The large amounts of cattle and pig manure are explained by both high number of animals and the high share of slurry produced (the highest amount per animal of the manure types). Very dry poultry manure is produced in significantly lower amount (0.241 million tons, 1.9%) but due to its high nutrient content, its share of manure nitrogen (5 737 t, 7.9%) and of manure phosphorus (2 315 t, 15%) is significant. Horse manure is produced in a higher amount (0.640 million tons, 5.0%), but its nutrient content is low (nitrogen: 2 700 t, 3.7%; phosphorus: 480 t, 3.2%). There is very little sheep and goat manure (0.103 million tons, 0.8%) and its nutrients (nitrogen: 730 t, 1.0%; phosphorus: 145 t, 1.0%). The fur animal manure is not a major amount (0.112 million t, 0.9%), but its nutrient content is high (nitrogen: 3 300 t, 4.6%; phosphorus: 1 491 t, 9.9%).

The spatial distribution of livestock manure and the animal categories present in different ELY-regions are seen in Figures 7 and 8. Finnish livestock production is much focused on cattle production with dairy cattle being predominant. The main regions for cattle production are North Savo, North Ostrobothnia, Ostrobothnia and South Ostrobothnia, though cattle farms are located all over the country. The highest pig production is in Southwest Finland, Ostrobothnia and South Ostrobothnia. Poultry production is mainly located in Southwest Finland, Satakunta and South Ostrobothnia. While the location of horse stables and sheep and goat production is more scattered, fur animal farms are very concentrated to especially Ostrobothnia, but also somewhat to South and North Ostrobothnia.

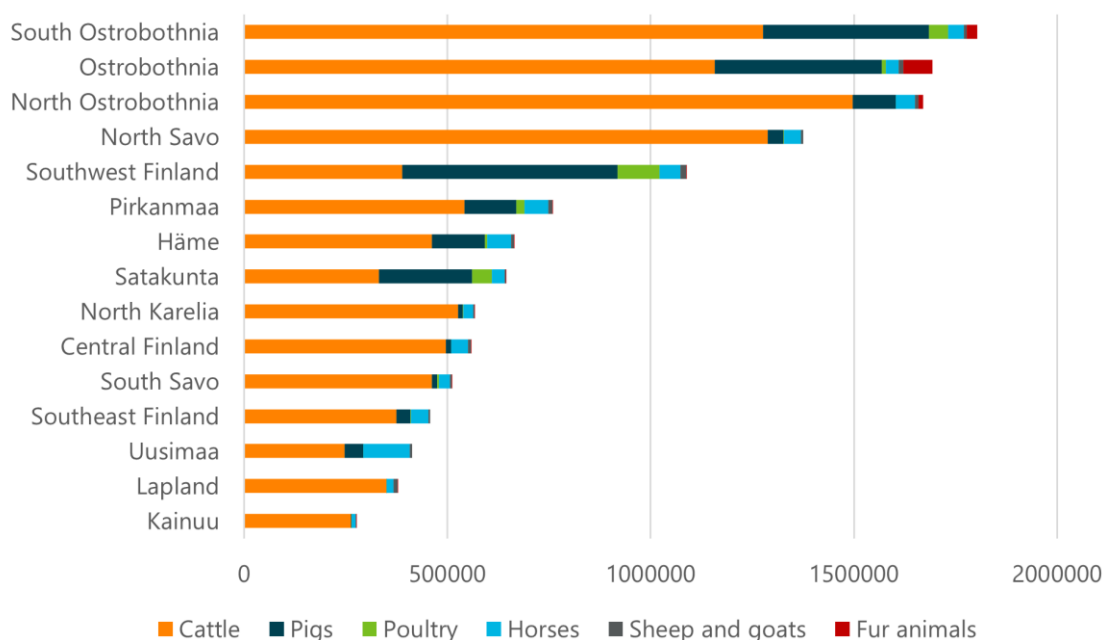


Figure 7. Livestock manure (tons/year) per animal category produced in the regions of Finnish ELY-Centres.

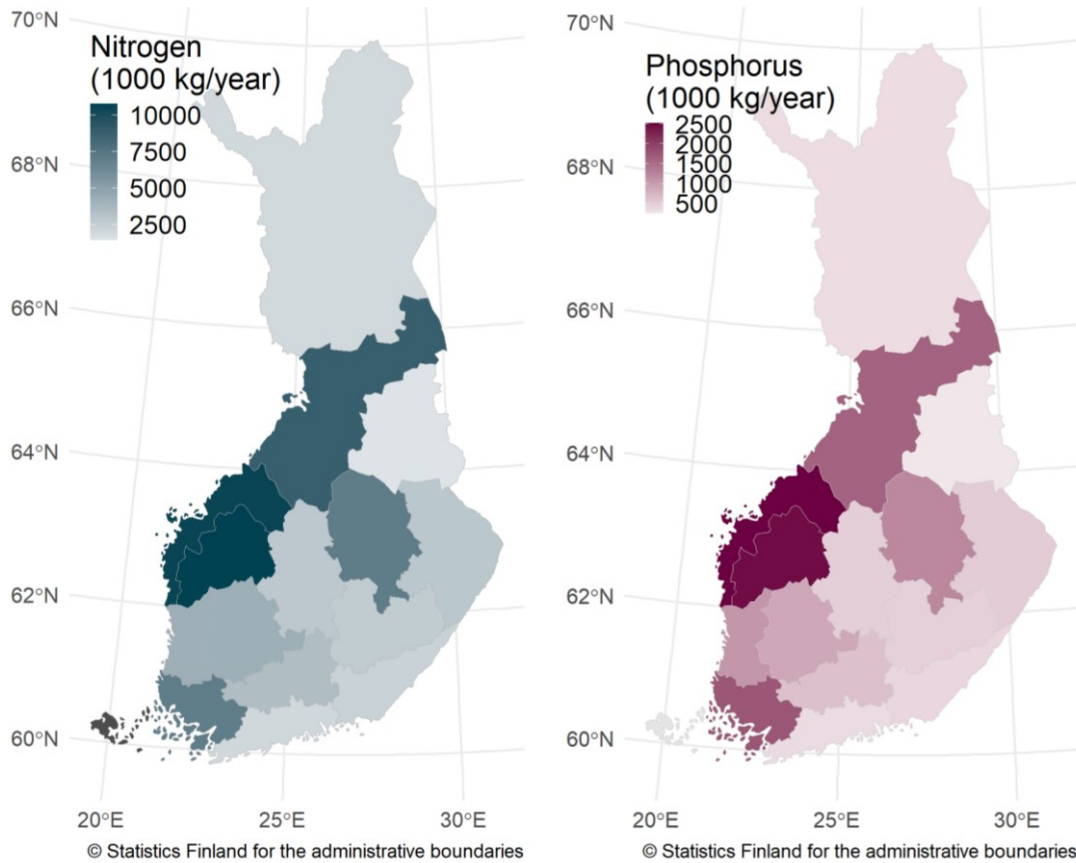


Figure 8. Spatial distribution of nitrogen (left) and phosphorus (right) in livestock manure in Finland (2020).

The Finnish manure data is available also on municipal level. This gives a more detailed insight into the spatial distribution of manure nutrients. Within the ELY-regions, there is variation in how evenly the livestock farms are located over their area, and just by looking at the amount of manure per ELY-region the actual regions of dense animal populations are not identified. Therefore, the Finnish manure production is also available per municipality. In Figure 9, the manure phosphorus is compared to utilized agricultural area as an example of this more detailed spatial resolution.

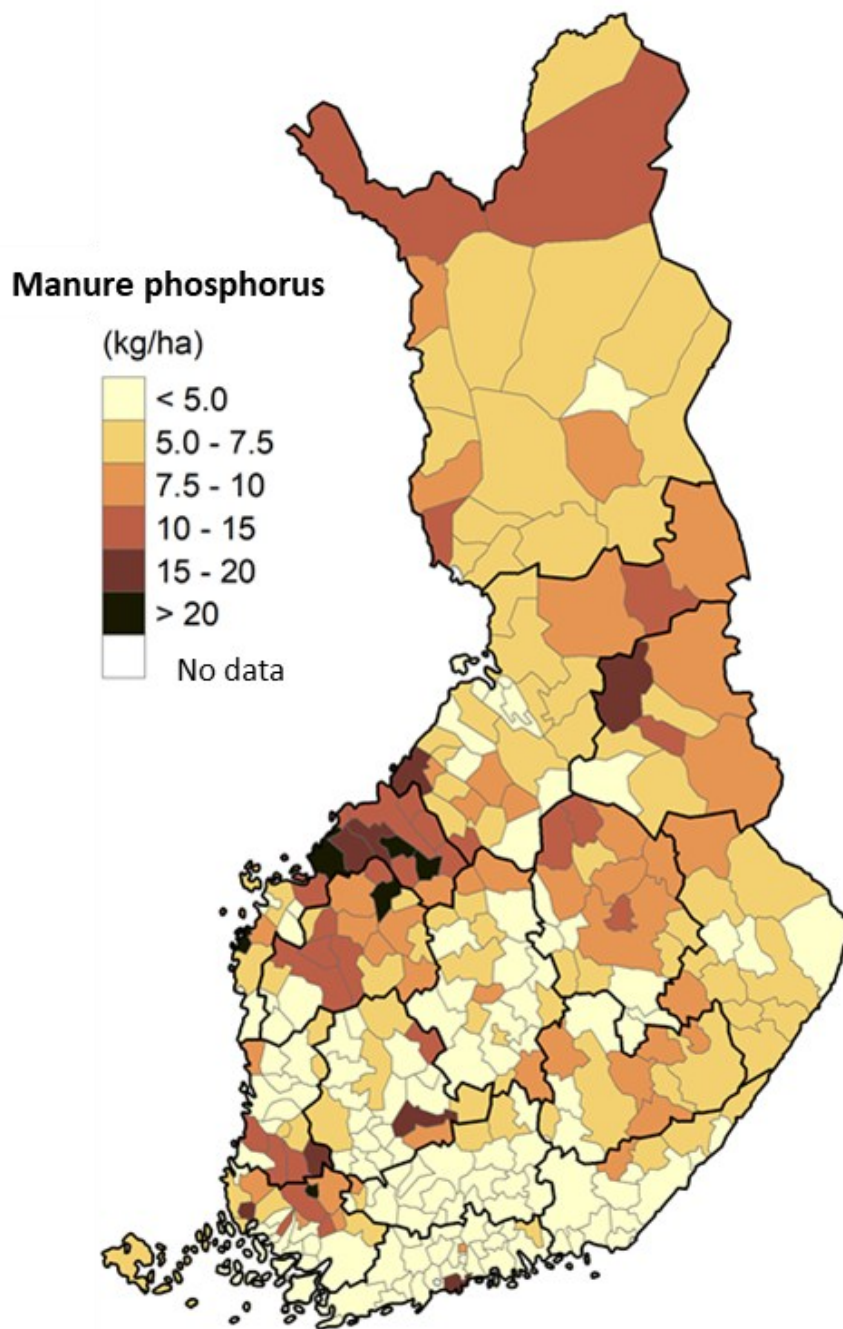


Figure 9. The amount of manure phosphorus per hectare of utilized agricultural area per Finnish municipality. The borders of ELY-Centres are shown in black and borders of municipalities in grey (published originally in Lemola et al. 2023).

Municipal and industrial wastes and side streams

The spatial distribution of municipal wastes (biowaste and sewage sludge) is dependent on population figures per region (Figures 10 & 11). The highest share is in Uusimaa, which hosts 32% of all Finnish population.

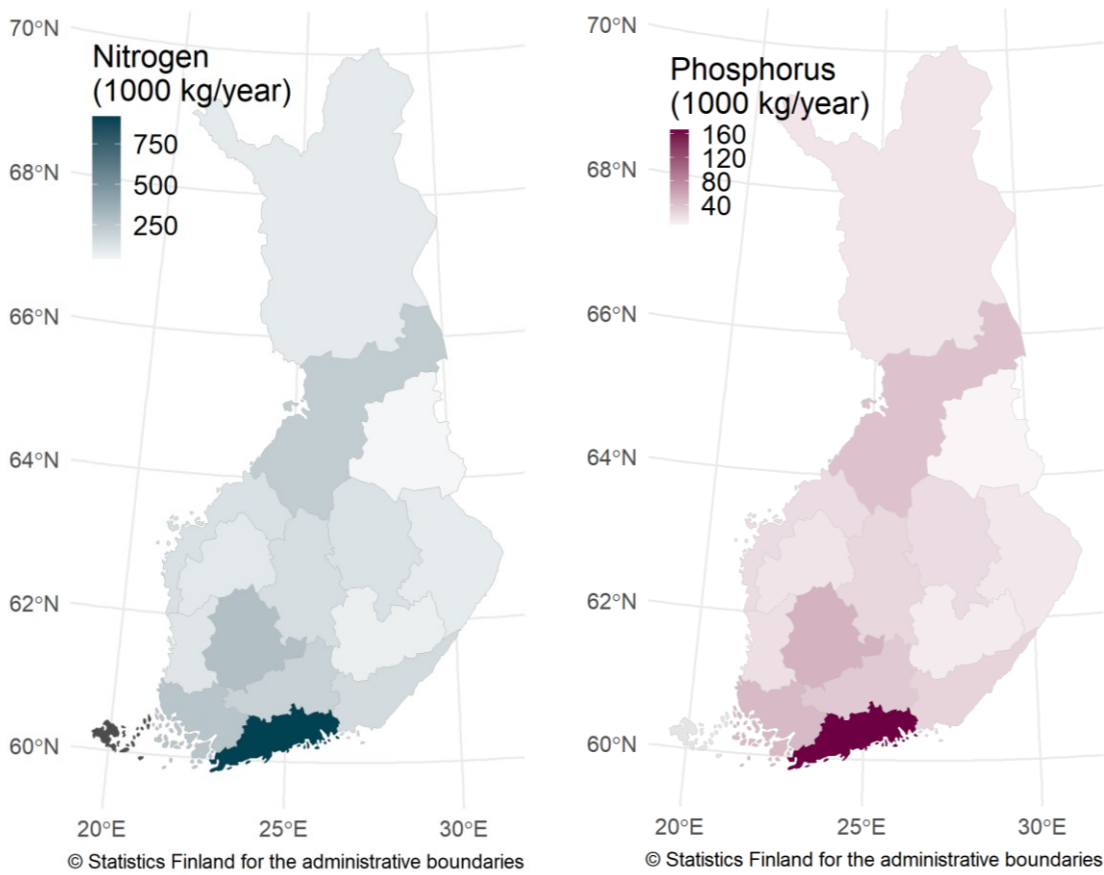


Figure 10. Spatial distribution of nitrogen (left) and phosphorus (right) in municipal biowaste in Finland (2020).

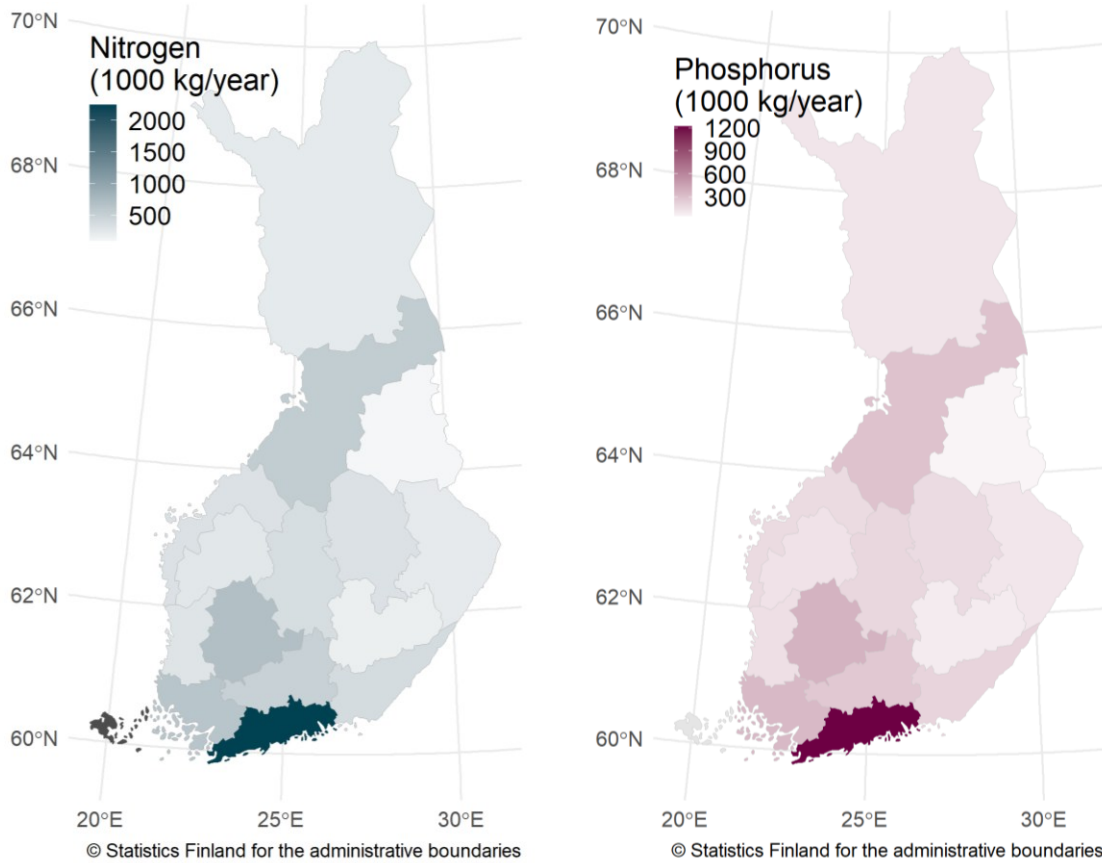


Figure 11. Spatial distribution of nitrogen (left) and phosphorus (right) in sewage sludge in Finland (2020).

The spatial distribution of animal by-products is dependent the livestock farms and on companies focused on slaughtering. In Finland, animals died on farm are collected and transported to a centralized rendering plant (except from farms located in remote regions). The main share of animal by-products is in South Ostrobothnia due to the high amount of livestock farms as well as concentration of meat-industries in the region (Figure 12). Food industry is more spread around the country (Figure 13).

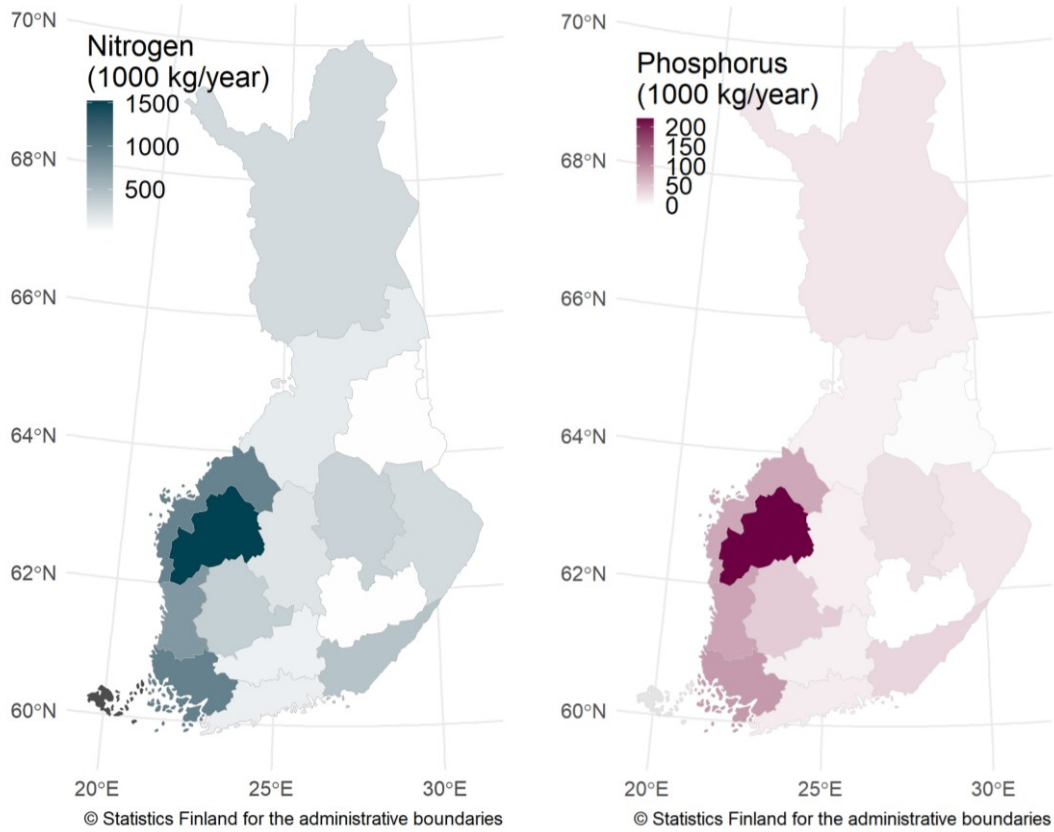


Figure 12. Spatial distribution of nitrogen (left) and phosphorus (right) in animal by-products in Finland (2020).

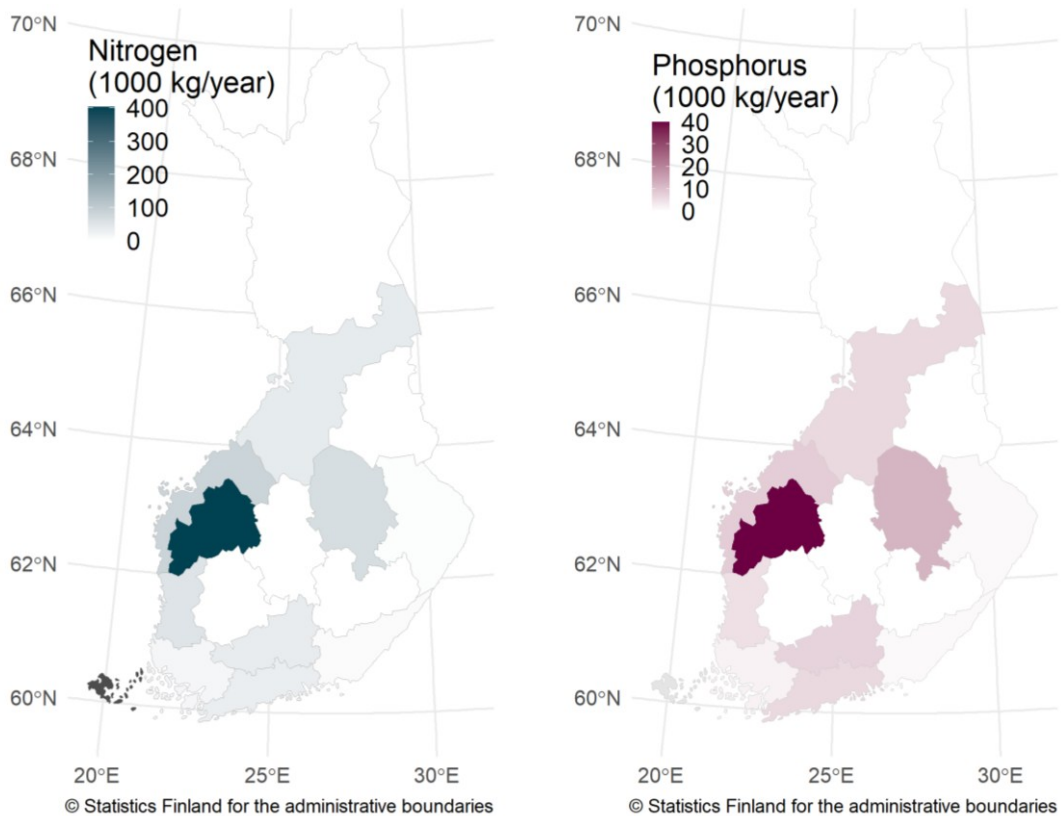


Figure 13. Spatial distribution of nitrogen (left) and phosphorus (right) in food industry side streams in Finland (2020).

When all the abovementioned biomasses are summed up, the spatial distribution of nutrients in Finnish recyclable biomasses still mostly reflects the spatial distribution of manure nutrients (Figure 14). Also, the most populated areas become more visible with especially Uusimaa region where the capital of Helsinki and its surrounding cities are located.

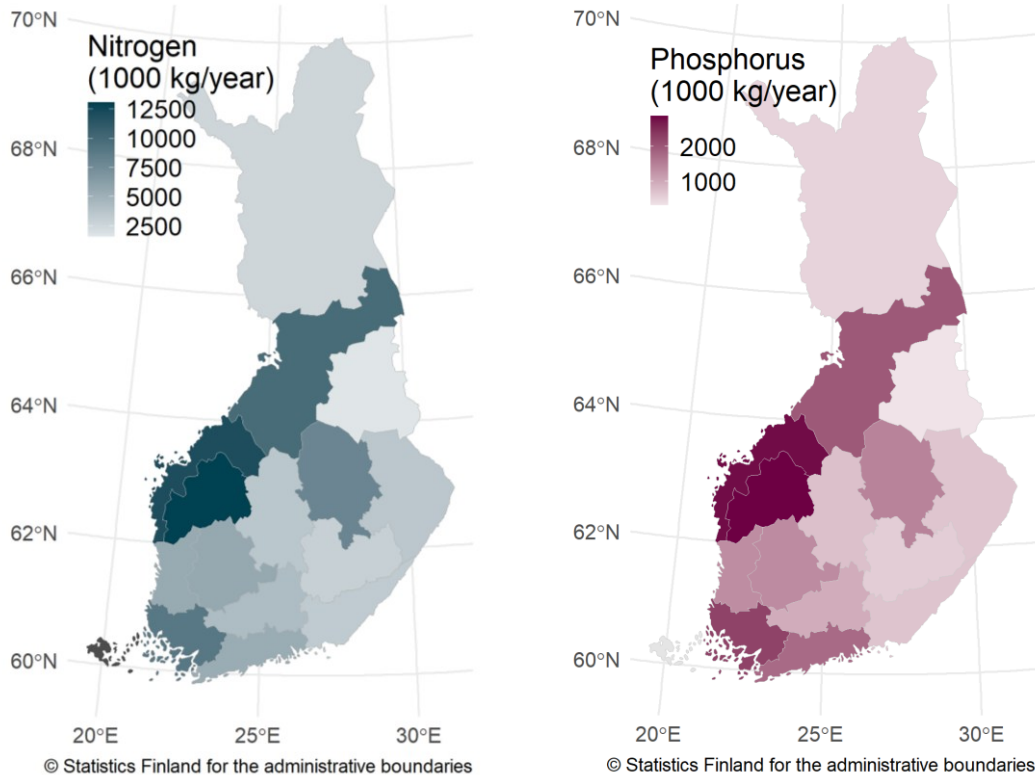


Figure 14. Spatial distribution of total nitrogen and phosphorus in all recyclable biomasses (manure, sewage sludge, municipal biowaste, animal by-products and food processing side streams) in Finland (2020).

Data collection for estimating nutrient recycling potential

While the method for calculating nutrient recycling potential in Finland is currently quite established and the background data needed available to a satisfactory degree. However, the quality of the data could still be better.

For one, the workload of organising the data especially for the industrial side-streams is high. The waste statistics rely on reports from the operators producing and/or receiving waste streams, due to which the quality of their reports and subsequently the entire dataset varies. It contains clear mistakes and inadequacies making the categorisation of the waste streams difficult. Also, the data collection behind waste statistics has been created to serve environmental authorities. It does not fully comply with the needs of calculating nutrient recycling potential, let alone monitoring the progress of nutrient recycling in Finland (discussed in Luostarinen (ed.) 2025).

The quality of the data on livestock manure is satisfactory. The challenges lie in smaller issues, such as comprehensive horse registry and sufficiently regular updating of Finnish Normative Manure System. The current horse registries in Finland lack proper connection between the horses and the stables where they are kept. The best registry on the number of horses (Hippos) offers the location data of the horse owners which may be quite different than where

the horses are really kept. The updating of the Finnish Normative Manure System, from where the manure data is taken, does not have a proper maintenance and updating system, but relies more on the processes of emission inventories. A thorough updating should be organised to ensure all the latest data is used in the calculation.

References

- Grönroos, J., Munther, J. & Luostarinen, S. 2017. Calculation of atmospheric nitrogen and NMVOC emissions from Finnish agriculture : Description of the revised model. Reports of the Finnish Environment Institute 37/2017. Helsinki. <http://hdl.handle.net/10138/-229364>
- Luostarinen, S., Grönroos, J., Hellstedt, M., Nousiainen, J. & Munther, J. 2017a. Suomen normilanta -laskentajärjestelmän kuvaus ja ensimmäiset tulokset. Luonnonvara- ja biotalouden tutkimus 47/2017. Luonnonvarakeskus, Helsinki. <http://urn.fi/URN:ISBN:978-952326-441-0>
- Luostarinen, S., Perttilä, S., Nousiainen, J., Hellstedt, M., Joki-Tokola, E. & Grönroos, J. 2017b. Turkiseläinten lannan määrä ja ominaisuudet. Tilaseurannan ja lantalaskennan tulokset. Luonnonvara- ja biotalouden tutkimus 46/2017. Luonnonvarakeskus, Helsinki. <http://urn.fi/URN:ISBN:978-952-326-439-7>
- Luostarinen, S., Laakso, J., Tampio, E., Skyttä, A. & Lehtonen, E. 2023. Ravinteiden kierrätyksen tilastointi ja seuranta : Ensimmäinen indikaattori ja kehittämisehdotukset. Luonnonvara- ja biotalouden tutkimus 107/2023. Luonnonvarakeskus, Helsinki. <http://urn.fi/URN:ISBN:978-952-380-823-2>
- Luostarinen, S. (ed.) 2025. Nutrient recycling in the Baltic Sea Region: state-of-the-art and the way forward. CiNURGi project report. <https://zenodo.org/records/17483354>
- MMM 2011. Suomesta ravinteiden kierrätyksen mallimaa. Työryhmämuistio MMM2011:5. Helsinki. <http://urn.fi/URN:ISBN:978-952-453-649-3>
- Official Statistics of Finland (OSF). Waste statistics [online publication]. ISSN=2323-5314. Helsinki: Statistics Finland [Referenced: 16.12.2022]. Access method: <https://stat.fi/en/statistics/jate>

3.2. Estonia

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For general description and finding potential sources for nutrient recycling in Estonia, the data on recyclable biomasses were collected, in addition to the whole country (which is also NUTS3 for Estonia), for smaller administrative regions, i.e. counties (Figure 15). The numbers of population are given according to the Estonian Statistics for year 2024 (Table 4).

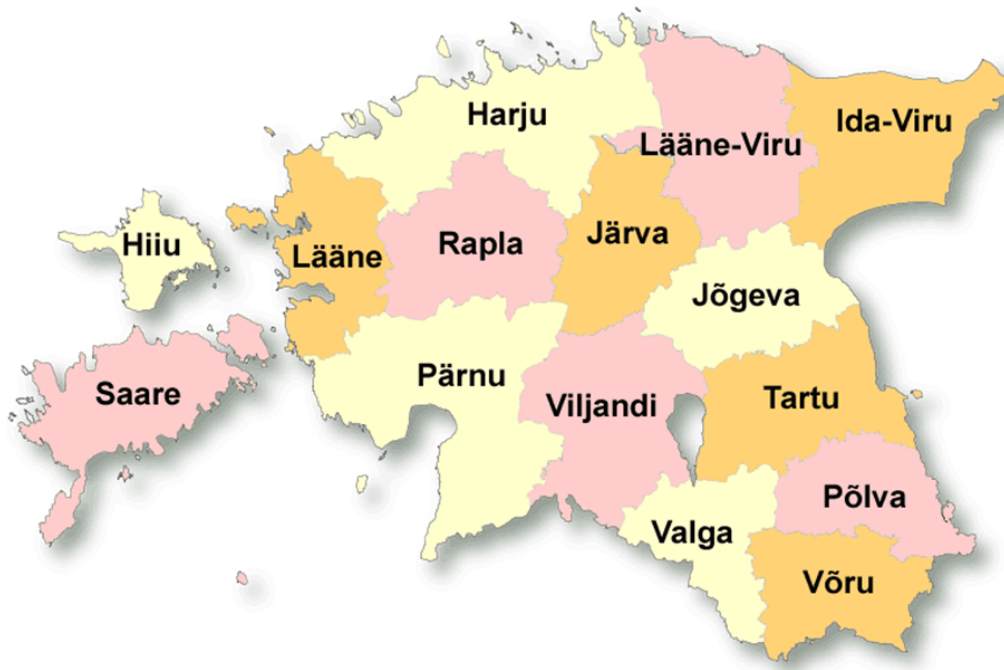


Figure 15. The map of counties of Estonia (Wikimedia Commons 2005).

3.2.1. Materials and methods

Livestock manure

The amount of manure and its nitrogen and phosphorus contents is calculated according to the animal species, age or production group for indoor rearing (Table 4, RT lisa3) and for grazing animals (Table 5, RT lisa4). For all animals, the number of batches per animal place is from RT lisa2. These values are taken from the Estonian Water Act regulation "Calculated values of nutrient content in different types of manure, conversion coefficients for livestock units and methodology for calculating manure storage capacity".

Table 4. Total amount and nutrient content of different manure types after storage in indoor rearing all year.

Animal species, age or production group	No of batches per year	Manure type (dry matter content %)	Amount of manure and nutrient content		
			amount, t/a	N, kg	P, kg
Dairy cows	1	Slurry (≤ 7.9)	24.7	116.9	30.1
		Solid manure (20.0–24.9)	21.8	95.1	29.8
		Deep litter (≥ 25)	22.6	122.7	33.1
Female calves (up to 6 month)	2	Slurry (≤ 7.9)	2.7	14.4	2.1
		Deep litter (≥ 25)	2.8	16.4	2.6
Bull calves (up to 6 month)	2	Slurry (≤ 7.9)	2.5	10.9	1.3
		Deep litter (≥ 25)	2.6	13.9	1.8
Heifers (6 month to calving)	1	Slurry (≤ 7.9)	11.1	49.2	11.1
		Solid manure (20.0–24.9)	11.6	45.4	11.3
		Deep litter (≥ 25)	13.2	63.8	14.1
Fattening pigs	3.2	Slurry (≤ 7.9)	0.5	2.6	0.6
		Deep litter (≥ 25)	0.6	3.3	0.7
Weaner pigs	6.4	Slurry (≤ 7.9)	0.1	0.6	0.1
Sows (with piglets)	1	Slurry (≤ 7.9)	3.7	20.3	5.4
Young sows	1.9	Slurry (≤ 7.9)	1.3	6.8	1.7
Boars	1	Slurry (≤ 7.9)	3.4	6.2	1.6
Laying hens (100 birds)	1	Deep litter (≥ 25)	4.8	54.4	16.0
Broilers (1000 birds)	7.5	Deep litter (≥ 25)	4.2	39.5	16.1
Young chickens (100 birds)	2.2	Deep litter (≥ 25)	0.9	7.3	3.3

Table 5. Total amount and nutrient content of different manure types after storage in the case of grazed animals.

Animal species, age or production group	No of batches per year	Manure type (dry matter content, %)	Amount of manure and nutrient content		
			amount, t/a	N, kg	P, kg
Suckler cows, beef cattle (over 24 months)	1	Slurry (≤ 7.9)	3.7	27.1	3.1
		Solid manure (20.0–24.9)	4	24.8	3.3
		Deep litter (≥ 25)	4.8	33.9	4.5
Female calves (up to 6 month)	2	Slurry (≤ 7.9)	2.2	11.8	1.8
		Deep litter (≥ 25)	2.3	13.7	2.2
Bull calves (up to 6 month)	2	Slurry (≤ 7.9)	2.1	9.1	1.1
		Deep litter (≥ 25)	2.2	11.6	1.5
Bulls (6 month to realization)	1.3	Slurry (≤ 7.9)	4.6	22.7	4.6
		Solid manure (20.0–24.9)	4.7	20.8	4.6
		Deep litter (≥ 25)	7.2	39.1	7.8
Heifers (6 month to calving)	1	Slurry (≤ 7.9)	7.4	33.0	7.5
		Solid manure (20.0–24.9)	7.8	30.5	7.6
		Deep litter (≥ 25)	8.9	42.8	9.5
Sheep with up to one-year-old lamb, other sheep	1	Deep litter (≥ 25)	1.4	9.6	1.7
Goat with up to one-year-old goatling, other goat	1	Deep litter (≥ 25)	2.1	14.3	2.6
Horse with up to six-month-old foal, other horse	1	Deep litter (≥ 25)	4.1	27	6.6

Cattle

The number of cattle (31.12.2023) is from a query from Paying Agency of Estonia (PRIA, cattle 2023). The number is divided into six groups: dairy cows, suckler cows, heifers (6 month to calving), bulls (6 month to realization), female calves (up to 6 month), bull calves (up to 6 month). Number of dairy cattle is given in Table 6 and number of beef cattle is given in Table 7. The share of different types of manure for the different cattle is given in Table 8, and the amount of different manure types (t/year) and amounts of N and P produced annually in Estonia are calculated by formulas given in Table 9.

Table 6. Number of dairy cattle in Estonia in 2023 (PRIA, cattle 2023).

Region	Dairy cows	Female calves (up to 6 month)	Heifers (6 month to calving)	Bull calves (up to 6 month)	Bulls (6 month to realization)
Estonia	83 266	21567	56 151	5 264	4 430
Harju county	3 814	907	2 779	223	170
Hiiu county	597	135	422	46	46
Ida-Viru county	1 066	219	745	101	89
Jõgeva county	7 336	1 989	5 268	287	123
Järva county	13 418	3 808	9 177	1 207	627
Lääne county	937	175	670	81	148
Lääne-Viru county	10 703	3 002	7 185	461	330
Põlva county	5 691	1 490	3 326	610	238
Pärnu county	10 100	2 384	6 243	407	304
Rapla county	6 593	1 647	4 814	390	173
Saare county	5 166	1 179	3 462	248	303
Tartu county	5 385	1 329	3 839	192	123
Valga county	3 798	951	2 345	391	563
Viljandi county	6 792	1 951	4 569	414	682
Võru county	1 870	401	1 307	206	511

Table 7. Number of beef cattle in Estonia in 2023 (PRIA, cattle 2023).

Region	Suckler cows	Female calves (up to 6 month)	Heifers (6 month to calving)	Bull calves (up to 6 month)	Bulls (6 month to realization)
Estonia	28 764	3 569	22 212	3 590	12 642
Harju county	2 211	245	2 121	204	1 404
Hiiu county	1 642	139	1 115	164	531
Ida-Viru county	908	150	728	131	449
Jõgeva county	519	78	401	86	265
Järva county	997	340	730	307	408
Lääne county	2 152	274	1 655	281	806
Lääne-Viru county	2 609	356	1 659	390	731
Põlva county	984	202	724	203	458
Pärnu county	4 612	386	3 398	411	1 683
Rapla county	1 770	233	1 427	213	898
Saare county	4 559	516	3 258	530	2 035
Tartu county	917	64	805	88	623
Valga county	1 616	157	1 444	155	830
Viljandi county	1 606	262	1 469	255	789
Võru county	1 662	167	1 278	172	732

Table 8. The share of different types of manure according to animal groups, in Estonia (Kaasik 2020).

Manure type	Dairy cows	Suckler cows	Heifers (6 month to calving)	Bulls (6 month to realization)	Female calves (up to 6 month)	Bull calves (up to 6 month)
Slurry	0.904	0.067	0.543	0.195	0.255	0.026
Solid manure	0.073	0	0.056	0.002	0	0
Deep litter	0.023	0.933	0.401	0.803	0.745	0.974

Table 9. Formulas to calculate the amount and nutrient contents of different manure types.

Type of manure	Formulas to calculate amount of manure	Formulas to calculate amount of N	Formulas to calculate amount of P
General	$w = \sum_{i=1}^n a_i w_i k_i$ $w_i = b_i w_{r,i}$	$w_N = \sum_{i=1}^n a_i N_i k_i$ $N_i = b_i N_{r,i}$	$w_P = \sum_{i=1}^n a_i P_i k_i$ $P_i = b_i P_{r,i}$
Cattle solid manure	$w_{cm} = \sum_{i=1}^n a_i w_{cm,i} k_{cm,i}$	$w_{cm,N} = \sum_{i=1}^n a_i N_{cm,i} k_{cm,i}$	$w_{cm,P} = \sum_{i=1}^n a_i P_{cm,i} k_{cm,i}$
Cattle slurry	$w_{cs} = \sum_{i=1}^n a_i w_{cs,i} k_{cs,i}$	$w_{cs,N} = \sum_{i=1}^n a_i N_{cs,i} k_{cs,i}$	$w_{cs,P} = \sum_{i=1}^n a_i P_{cs,i} k_{cs,i}$
Pig solid manure	$w_{pm} = \sum_{i=1}^n a_i w_{pm,i} k_{pm,i}$	$w_{pm,N} = \sum_{i=1}^n a_i N_{pm,i} k_{pm,i}$	$w_{pm,P} = \sum_{i=1}^n a_i P_{pm,i} k_{pm,i}$
Pig slurry	$w_{ps} = \sum_{i=1}^n a_i w_{ps,i} k_{ps,i}$	$w_{ps,N} = \sum_{i=1}^n a_i N_{ps,i} k_{ps,i}$	$w_{ps,P} = \sum_{i=1}^n a_i P_{ps,i} k_{ps,i}$
Poultry manure	$w_{plm} = \sum_{i=1}^n a_i w_{plm,i}$	$w_{plm,N} = \sum_{i=1}^n a_i N_{plm,i}$	$w_{plm,P} = \sum_{i=1}^n a_i P_{plm,i}$

a_i is the number of animal in animal group i (Table 6 and 7 for cattle and Table 10 for pigs); for calculation of poultry manure the number of birds in group i is taken form Table 12, for layng hens and young hens a_i is divided by 100 and for broilers a_i is divided by 1000;

cm notes cattle solid manure;

cs notes cattle slurry;

i is index of an animal group, (Table 6 for cattle, Table 10 for pigs);

k_i is the share of manure by animal group i (Table 6 for cattle, Table 10 for pigs);

n is number of the animal groups, (Table 6 for cattle, Table 10 for pigs);

N_i is the amount of N produced by one animal place in group i (kg/year/animal) (Table 4 and Table 5);

P_i is the amount of P produced by one animal place in group i (kg/year/animal) (Table 4 and Table 5);

pm notes pig solid manure;

ps notes pig slurry;

plm notes poultry solid manure;

w is the annual weight of manure (t/year);

w_i is the annual weight of manure produced by one animal place in group i , (t/year/animal) (Table 4 and Table 5);

w_N is the annual weight of N in manure produced by animal, (kg/year);

w_P is the annual weight of P in manure produced by animal, (kg/year);

b_i is number of production rounds per production place for animal group i (Table 4 and Table 5)

$w_{r,i}$ is the amount of manure produced by group i per one production round per one animal

$N_{r,i}$ is the amount of N produced by group i per one production round per one animal;

$P_{r,i}$ is the amount of P produced by group i per one production round per one animal;

$w_{plm,i}$ is the annual weight of manure produced by birds (100 or 1000 birds) in group i (Table 4);

$N_{plm,i}$ is the amount of N produced by birds (100 or 1000 birds) in group i (kg/year) (Table 4);

$P_{plm,i}$ is the amount of P produced by birds (100 or 1000 birds) in group i (kg/year) (Table 4).

Pigs

The number of pigs (31.12.2023) is from a query from Paying Agency of Estonia (PRIA, pigs 2023). The number of pigs is divided into five groups: fattening pigs, weaner pigs, sows with piglets, young sows, and boars (Table 10). The share of different manure types are given in Table 11. The amount and nutrient content of pig manures is calculated using the formulas in Table 9.

Table 10. Number of pigs in Estonia, 2023 (PRIA, pigs 2023).

Region	Fattening pigs	Weaner pigs	Sows with piglets	Young sows	Boars
Estonia	152 245	98 368	16 965	7 133	251
Harju county	17 597	4 702	1 020	735	11
Hiiu county	0	0	0	0	1
Ida-Viru county	1 256	659	203	35	1
Jõgeva county	5 824	7 328	2 921	969	11
Järva county	1 256	2 603	449	368	5
Lääne county	5 205	2 392	408	287	12
Lääne-Viru county	28 479	16 082	2 496	1 128	25
Põlva county	13 075	1 892	0	0	0
Pärnu county	6 594	2 329	29	5	6
Rapla county	8 640	1 277	0	0	0
Saare county	13 687	10 837	1 889	625	27
Tartu county	17 800	787	467	265	68
Valga county	10	6	6	3	1
Viljandi county	31 080	39 857	6 886	2 609	72
Võru county	1 742	7 617	191	104	11

Table 11. The share of different type of manure according to the pig type in Estonia (Kaasik 2020, Table 6).

Manure type	Fattening pigs	Weaner pigs	Sows	Boars
Slurry	0.932	1	1	1
Solid manure	0	0	0	0
Deep litter	0.068	0	0	0

Poultry

The number of poultry (Table 12) is available only for the entire Estonia, not by country. All poultry manure is deep litter and the amount and nutrient content is calculated using the formulas in Table 9.

Table 12. Number of poultry in Estonia in 2023 (Statistics Estonia 2024c).

Region	Laying hens	Broilers	Young chickens	Ducks	Geese	Turkeys
Estonia	662 500	1 292 000	177 600	1 119	547	1 536

Sheep and goats

The number of sheep and goats by county in Estonia is taken from Estonia Statistics (Table 13).

Table 13. Number of sheep and goats in Estonia in 2023 (Estonia Statistics 2024c).

Region	Sheep	Goats
Estonia	55 100	3 700
Harju county	3 100	200
Hiiu county	2 600	100
Ida-Viru county	800	200
Jõgeva county	700	100
Järva county	1 600	200
Lääne county	2 500	200
Lääne-Viru county	5 300	200
Põlva county	2 700	100
Pärnu county	5 100	1 000
Rapla county	5 900	200
Saare county	10 600	200
Tartu county	3 400	200
Valga county	3 100	100
Viljandi county	3 500	100
Võru county	4 200	600

The number of sheep, goats and horses solid manure (t/year) is calculated by the following formula:

$$w_{sm} = a_s w_m \tag{1}$$

where

w_{sm} is the annual weight solid manure (t/year);

a_s is the number of animal (Table 14 for sheep and goats, Table 16 for horses);

w_m is the annual weight of manure produced by one animal (t/year/animal) (Table 3);

Amount of N and P is calculated by formulas

$$w_{sm,N} = a_s N_m \tag{2}$$

$$w_{sm,P} = a_s P_m \tag{3}$$

N_m is the amount of N produced by one animal (kg/year/animal) (Table 5);

P_m is the amount of P produced by one animal (kg/year/animal) (Table 5).

Horses

The number of horses (3.6.2024, Table 14) is taken from Paying Agency of Estonia (PRIA, horses 2024). The amount of solid manure produced by the horses is calculated similarly as that of sheep and goats.

Table 14. Number of horses in Estonia, 2024 (PRIA, horses 2024).

Region	Horses
Estonia	13 756
Harju county	2 662
Hiiu county	1 077
Ida-Viru county	450
Jõgeva county	423
Järva county	526
Lääne county	670
Lääne-Viru county	627
Põlva county	330
Pärnu county	1 591
Rapla county	856
Saare county	1 650
Tartu county	1 256
Valga county	384
Viljandi county	623
Võru county	631

Municipal waste streams

The production of municipal sewage sludge on wastewater treatment plants and source-sorted municipal biowaste are connected to the size of the population per county (Table 23).

Sewage sludge

To calculate the amount of municipal sewage sludge produced in Estonia, the average amount produced per capita in 2022 is used (15.89 kg of dry matter per capita per year; Eurostat, env_ww_spd). This amount is multiplied with the population in Estonia in the beginning of 2024. The N and P contents in sewage sludge dry matter used in estimating the nutrient content are 3.85% and 2.6%, correspondingly (EC 2010).

$$W_{SS,N} = a_{SS} N_{SS} \quad (4)$$

$$W_{SS,P} = a_{SS} P_{SS} \quad (5)$$

where

$W_{SS,N}$ is amount of N in municipal wastewater sludge, t/year;

a_{SS} is the amount of sewage sludge, t/year (DM);

N_{SS} is the N content in sewage sludge, %DM;

$W_{SS,P}$ is amount of P in municipal wastewater sludge, t/year;

P_{SS} is the P content in sewage sludge, %DM.

Municipal source-sorted biowaste

The amount of municipal source-sorted biowaste is calculated using the average production per capita in 2017/2018 (16 kg/person/year; Favoino & Giavini 2020) as no newer information for Estonia was found. This amount is multiplied with the population in Estonia in the beginning of 2024. The N content in biowaste fresh matter is 0.74% (Banks et al. 2018). The P content in biowaste dry matter is 0.4% and the dry matter content in bio-waste is 24% in average (Banks et al. 2018).

$$w_{bw,N} = a_{bw} N_{bw} \quad (6)$$

$$w_{bw,P} = a_{bw} k P_{bw} \quad (7)$$

where

- $w_{bw,N}$ is amount of N in biowaste, t/year;
- a_{bw} is the amount of biowaste, t/year;
- N_{bw} is the N content in biowaste, %FM;
- $w_{bw,P}$ is amount of P in biowaste, t/year;
- P_{bw} is the P content in biowaste, %DM;
- k is the dry matter content of biowaste, %.

Industrial side streams

Animal by-products

The amount and nutrient content of Estonian animal by-products is estimated from the number of slaughtered animals (Eurostat, apro_mt_pann, 2023) as follows:

- Cattle: 69.42 thousand heads
- Pigs: 485.96 thousand heads
- Poultry: 2 211.8 thousand heads

The number of slaughtered animals is multiplied with the average of slaughter waste per head (Table 15) and then summed up for national total amount of animal by-products (t/a). The nutrient content of the animal by-products (Table 15) is then calculated as follows:

$$w_{ab,N} = a_{ab} N_{ab} \quad (8)$$

$$w_{ab,P} = a_{ab} P_{ab} \quad (9)$$

where

- $w_{ab,N}$ is amount of N in animal by-products, t/year;
- a_{ab} is the amount of slaughter waste, t/year;
- N_{ab} is the nitrogen content in animal, %FM (Table 15);
- $w_{ab,P}$ is amount of P in animal by-products, t/year;
- P_{ab} is the phosphorus content in animal, %FM (Table 15).

Table 15. Factors for calculating the amount and nutrient content of animal by-products (Finnish Environment Institute 2000).

Variable	Factor
Slaughter waste average of cattle per head	180 kg per animal
Nitrogen content of cattle slaughter waste	2.9% of FM
Phosphorus content of cattle slaughter waste	0.7% of FM
Slaughter waste average of pig per head	26 kg per animal
Nitrogen content of pig slaughter waste	2.5% of FM
Phosphorus content of pig slaughter waste	0.56 % of FM
Slaughter waste average of poultry per head	0.77 kg per animal
Nitrogen content of poultry slaughter waste	2.8% of FM
Phosphorus content of poultry slaughter waste	0.58% of FM

Food industry side streams

The data on the amount of food industry side streams (Table 16) are selected from Estonian portal for environmental data (Keskkonnaportaal 2022) by waste categories with the help of the list of waste categories in Estonian legislation (RT KKM_m65_lisa). The selection was made by Estonian experts participating in the CiNURGi project. The RNF potential of waste categories was also assessed by them.

Table 16. Categories of food industry side streams selected by CiNURGi experts. Dry matter, nitrogen and phosphorus contents of categories according to Luostarinen et al. (2023).

Explanation of waste categories	Waste type	* RNF potential	DM %	Ntot (%DM)	Ptot (%DM)
Waste from the production and processing of meat, fish and other food products of animal origin	02 02 02	1	35	9	0.7
Waste from the production and processing of meat, fish and other food products of animal origin	02 02 04	1	20	4	2
Wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	02 03 01	1	27	2	0.2
Wastes from the dairy products industry	02 05 02	1	6	5	1
Wastes from the dairy products industry	02 05 98	1	6	5	1
Wastes from the preparation of water intended for human consumption or water for industrial use	19 09 02	1	11	6	1.2
Waste from the production and processing of meat, fish and other food products of animal origin	02 02 03	2	27	2	0.2
Wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	02 03 04	2	27	2	0.2
Wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation	02 03 99	2	27	2	0.2
Wastes from the dairy products industry	02 05 01	2	6	5	1
Wastes from the baking and confectionery industry	02 06 01	2	75	2.2	0.3
Wastes from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)	02 07 04	2	11	6	1.2

* RNF potential: 1) yes, 2) requires clarification. This was assessed by Estonian experts participating in the CiNURGi project.

The nutrient content in food industry side streams is calculated as follows:

$$w_{fi,N} = a_{fi} N_{fi} \quad (10)$$

$$w_{fi,P} = a_{fi} P_{fi} \quad (11)$$

where

$w_{fi,N}$ is amount of N in food industry side streams, t/year;

a_{fi} is the amount of food industry side streams, t/year;

N_{fi} is the nitrogen content in food industry side streams, %DM (Table 16);

$w_{fi,P}$ is amount of P in food industry side streams, t/year;

P_{fi} is the phosphorus content in food industry side streams, %DM (Table 16).

3.2.2. Nutrient recycling potential in Estonia

Of all recyclable biomasses included in the Estonian calculation, livestock manure makes up the most with the other waste and side streams serving a significantly smaller share to the potential (Table 17).

Table 17. Total nutrient recycling potential in Estonia.

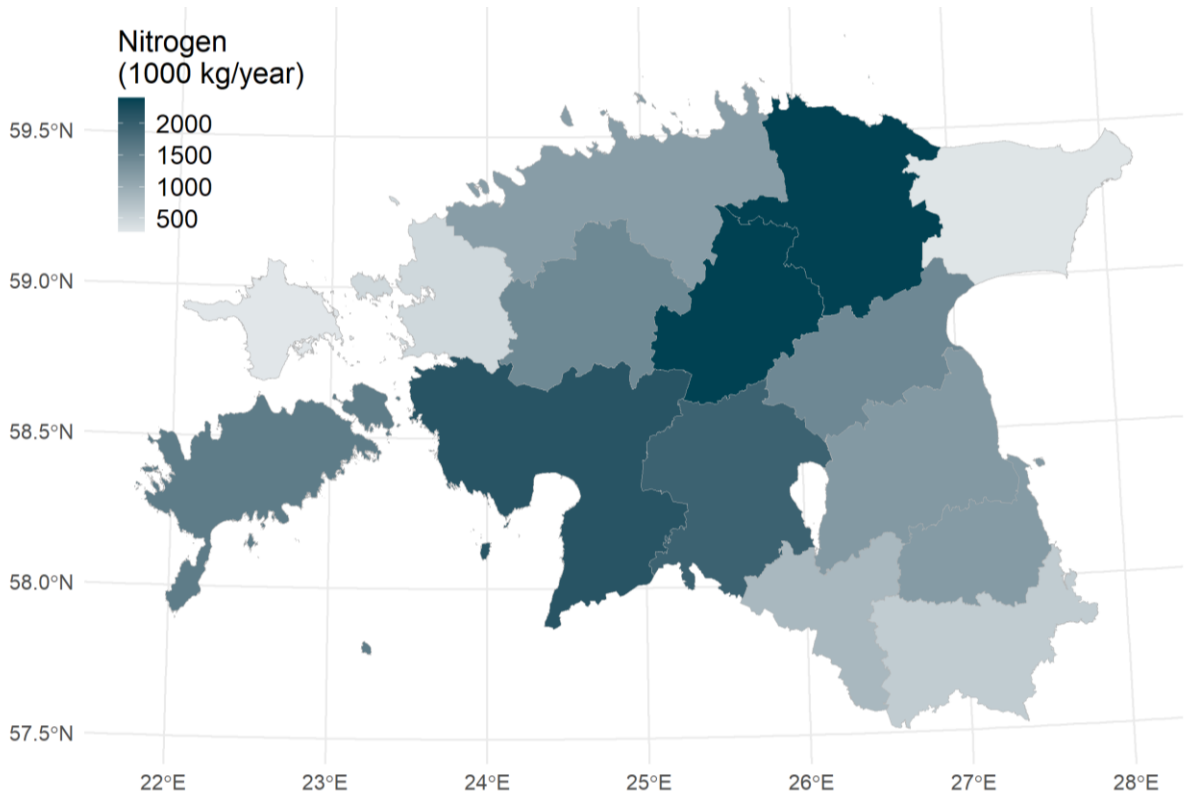
	Mass (t/a)	Ntot (t/a)	Ptot (t/a)
Livestock manure	3 948 042	20 104	4 764
Municipal biowaste	21 970	163	21
Sewage sludge	21 815	840	567
Animal by-products	26 834	726	168
Food industry side streams	78 296	531	166
Total	4 096 957	22 364	5 686

Livestock manure

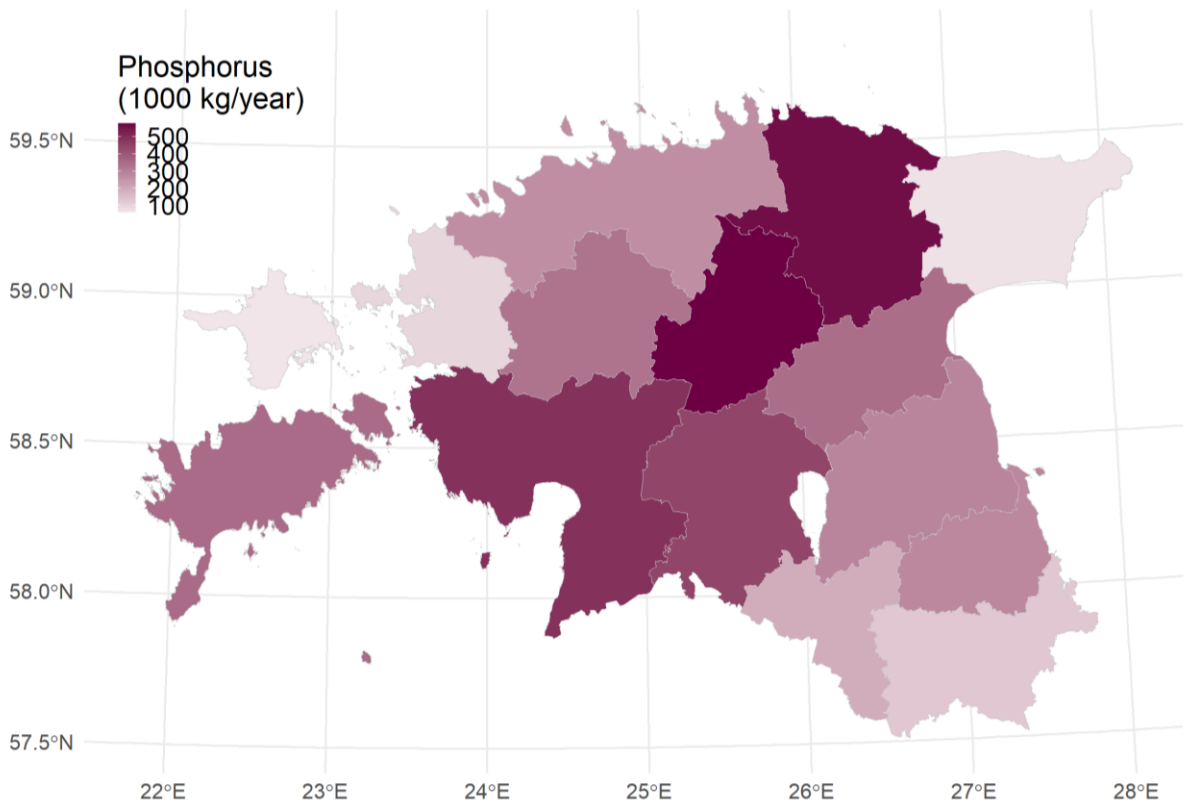
The livestock manure of 3.95 million tons per year contains 20 104 tons of nitrogen and 4 764 tons of phosphorus (Table 18). The total manure per county lacks data of poultry manure as the number of poultry is not available on the county level. Thus, the maps depicting the spatial distribution per county are not comprehensive (Figure 16). It can still be seen that much of the manure in Estonia is located in the counties of Järva, Lääne-Viru, Pärnu, Saare and Viljandi each with over 300 000 tons of manure.

Table 18. Total of livestock manure in Estonia in 2023.

Region	NUTS_ID	Manure TOTAL		
		Mass t/year	Nitrogen t/year	Phosphorus t/year
Estonia*	EE00	3 948 042	20 104	4 764
Harju county	0037	228 302	1 164	266
Hiiu county	0039	52 027	284	59
Ida-Viru county	0045	59 537	304	68
Jõgeva county	0050	294 766	1 430	346
Järva county	0052	498 764	2 397	577
Lääne county	0056	85 381	454	96
Lääne-Viru county	0060	483 338	2 391	561
Põlva county	0064	241 863	1 195	283
Pärnu county	0068	430 085	2 127	493
Rapla county	0071	288 268	1 423	333
Saare county	0074	307 861	1 591	353
Tartu county	0079	246 145	1 215	288
Valga county	0081	167 737	833	192
Viljandi county	0084	382 624	1 933	447
Võru county	0087	113 994	593	129



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Figure 16. Spatial distribution of nitrogen (above) and phosphorus (below) in livestock manure in Estonia. Note: the share of poultry manure is excluded as the data is not available on county level.

Most of the manure in Estonia is from cattle production (Table 19) comprising 85% of the total manure produced.

Table 19. The amounts of manure and nutrients in cattle slurry and solid manures in Estonia in 2023.

Region	NUTS_ID	Cattle slurry			Cattle solid manures		
		Mass	Nitrogen	Phosphorus	Mass	Nitrogen	Phosphorus
		t/year	t/year	t/year	t/year	t/year	t/year
Estonia	EE00	2 351 453	11 046.7	2 750.0	1 002 393	5 256.6	1 078.1
Harju county	0037	114 498	537.2	132.8	61 532	328.3	65.6
Hiiu county	0039	21 828	102.7	24.7	21 932	125.6	22.4
Ida-Viru county	0045	32 622	153.2	37.7	20 258	110.2	21.2
Jõgeva county	0050	200 704	942.0	235.9	64 098	319.9	71.0
Järva county	0052	365 511	1 716.7	429.7	122 858	617.9	134.1
Lääne county	0056	33 934	159.5	38.4	32 771	185.3	33.5
Lääne-Viru county	0060	295 687	1 389.2	346.9	109 537	566.7	119.0
Põlva county	0064	153 612	722.3	180.8	55 321	284.7	59.8
Pärnu county	0068	284 269	1 336.0	332.7	122 901	653.1	132.2
Rapla county	0071	186 365	874.6	218.0	74 883	387.5	81.1
Saare county	0074	155 643	731.6	180.3	92 924	508.3	97.8
Tartu county	0079	149 727	702.7	175.6	54 309	276.6	59.6
Valga county	0081	108 654	510.7	126.8	52 910	280.4	56.5
Viljandi county	0084	190 684	895.8	223.1	78 230	405.3	84.6
Võru county	0087	57 715	271.2	66.7	37 931	206.6	39.8

Pig manure comprises 9.7% of the total manure produced in Estonia, and it is located especially in the counties of Jõgeva, Lääne-Viru, Põlva, Saare, Tartu and Viljandi (Table 20).

Table 20. The amounts of manure and nutrients in pig slurry and solid manures in Estonia in 2023.

Region	NUTS_ID	Pig slurry			Pig solid manures		
		Mass	Nitrogen	Phosphorus	Mass	Nitrogen	Phosphorus
		t/year	t/year	t/year	t/year	t/year	t/year
Estonia	EE00	365 662	1967.3	443.2	19 877	109.3	23.2
Harju county	0037	34 303	181.8	41.6	2 297	12.6	2.7
Hiiu county	0039	3	0.0	0.0	0	0.0	0.0
Ida-Viru county	0045	3 108	16.7	3.8	164	0.9	0.2
Jõgeva county	0050	25 857	141.2	33.0	760	4.2	0.9
Järva county	0052	5 839	32.1	7.2	164	0.9	0.2
Lääne county	0056	11 328	60.4	13.7	680	3.7	0.8
Lääne-Viru county	0060	63 987	343.4	77.3	3 718	20.5	4.3
Põlva county	0064	20 708	108.7	24.6	1 707	9.4	2.0
Pärnu county	0068	11 460	60.7	13.5	861	4.7	1.0
Rapla county	0071	13 701	71.9	16.3	1 128	6.2	1.3
Saare county	0074	35 483	191.8	43.1	1 787	9.8	2.1
Tartu county	0079	29 454	153.3	35.6	2 324	12.8	2.7
Valga county	0081	49	0.3	0.1	1	0.0	0.0
Viljandi county	0084	101 987	557.4	124.2	4 058	22.3	4.7
Võru county	0087	8 392	47.6	9.3	227	1.3	0.3

The amount of poultry manure produced in Estonia comprises of 1.7% of total manure produced (Table 21). The data is only available on national level, not for counties.

Table 21. Poultry manure in Estonia in 2023.

Region	NUTS_ID	Poultry solid manure		
		Mass	Nitrogen	Phosphorus
		t/year	t/year	t/year
Estonia	EE00	67 347	771.7	274.9

The amount of horse manure makes up 1.4% of total manure produced in Estonia with the horse stables concentrating especially in the counties of Harju, Põlva, Saare and Tartu (Table 22).

Table 22. Horse manure in Estonia in 2024.

Region	NUTS_ID	Horse solid manure		
		Mass	Nitrogen	Phosphorus
		t/year	t/year	t/year
Estonia	EE00	56 400	371.4	90.8
Harju county	0037	10 912	71.9	17.6
Hiiu county	0039	4 414	29.1	7.1
Ida-Viru county	0045	1 845	12.2	3.0
Jõgeva county	0050	2 157	14.2	3.5
Järva county	0052	1 732	11.4	2.8
Lääne county	0056	2 748	18.1	4.4
Lääne-Viru county	0060	2 569	16.9	4.1
Põlva county	0064	6 525	43.0	10.5
Pärnu county	0068	1 354	8.9	2.2
Rapla county	0071	3 511	23.1	5.7
Saare county	0074	6 764	44.5	10.9
Tartu county	0079	5 151	33.9	8.3
Valga county	0081	1 573	10.4	2.5
Viljandi county	0084	2 555	16.8	4.1
Võru county	0087	2 589	17.0	4.2

Municipal waste streams

The amount and thus also the nutrient content of sewage sludge and municipal biowaste is tied to the Estonian population. This explains why they are concentrated in the counties with the highest population (Table 23; Figures 17 & 18).

Table 23. Municipal sewage sludge and municipal source-separated biowaste in Estonia.

Region	NUTS_ID	Population 1.1.2024	Sewage sludge			Municipal biowaste		
			Mass	N	P	Mass	N	P
			t/year	t/year	t/year	t/year	t/year	t/year
Estonia	EE00	1 373 101	21 815	839.86	567.18	21 970	162.58	21.09
Harju county	0037	647 174	10 282	395.85	267.33	10 355	76.63	9.94
Hiiu county	0039	9 758	155	5.97	4.03	156	1.16	0.15
Ida-Viru county	0045	130 362	2 071	79.74	53.85	2086	15.43	2.00
Jõgeva county	0050	27 608	439	16.89	11.40	442	3.27	0.42
Järva county	0052	29 611	470	18.11	12.23	474	3.51	0.45
Lääne county	0056	20 653	328	12.63	8.53	330	2.45	0.32
Lääne-Viru county	0060	58 328	927	35.68	24.09	933	6.91	0.90
Põlva county	0064	24 139	3 834	14.76	9.97	386	2.86	0.37
Pärnu county	0068	87 552	1 391	53.55	36.16	1 401	10.37	1.34
Rapla county	0071	33 986	540	20.79	14.04	544	4.02	0.52
Saare county	0074	34 379	546	21.03	14.20	550	4.07	0.53
Tartu county	0079	161 957	2 573.03	99.06	66.90	2 591	19.18	2.49
Valga county	0081	27 557	437.80	16.86	11.38	441	3.26	0.42
Viljandi county	0084	45 368	720.77	27.75	18.74	726	5.37	0.70
Võru county	0087	34 669	550.79	21.21	14.32	555	4.10	0.53

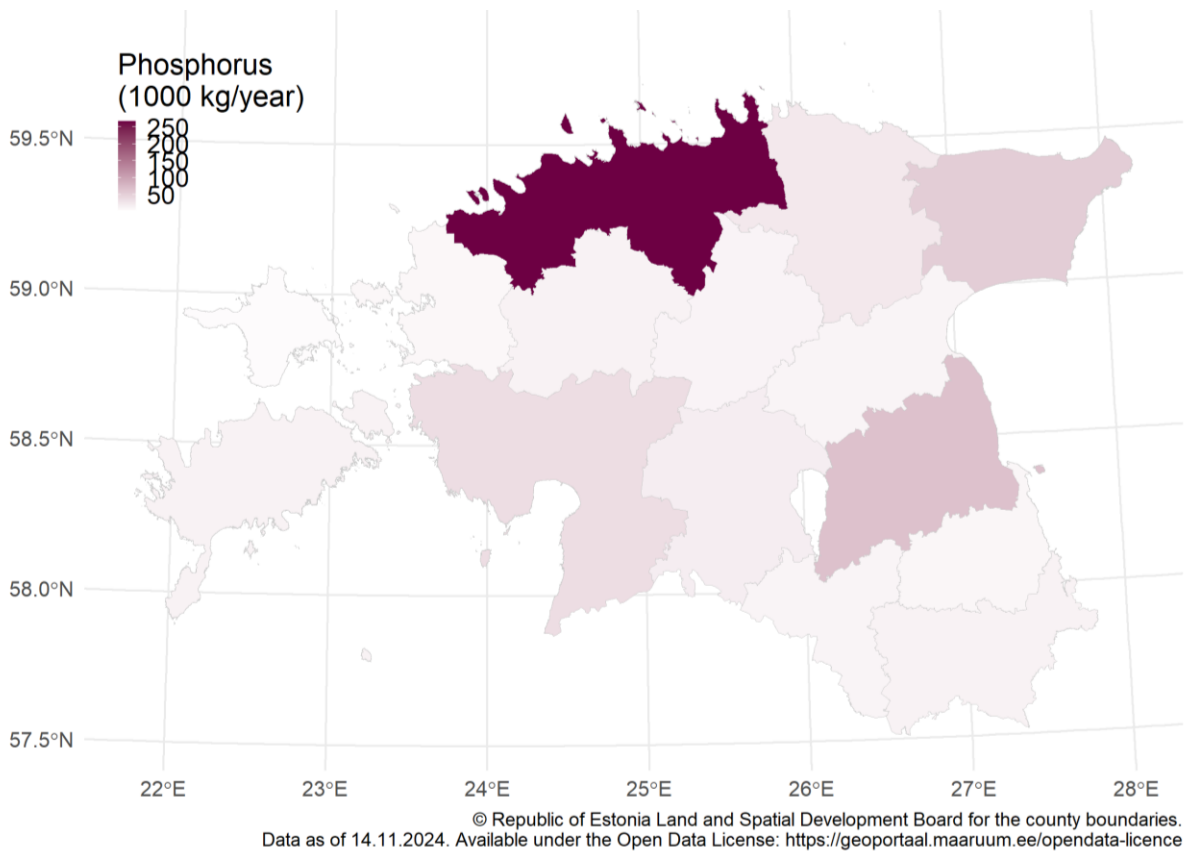
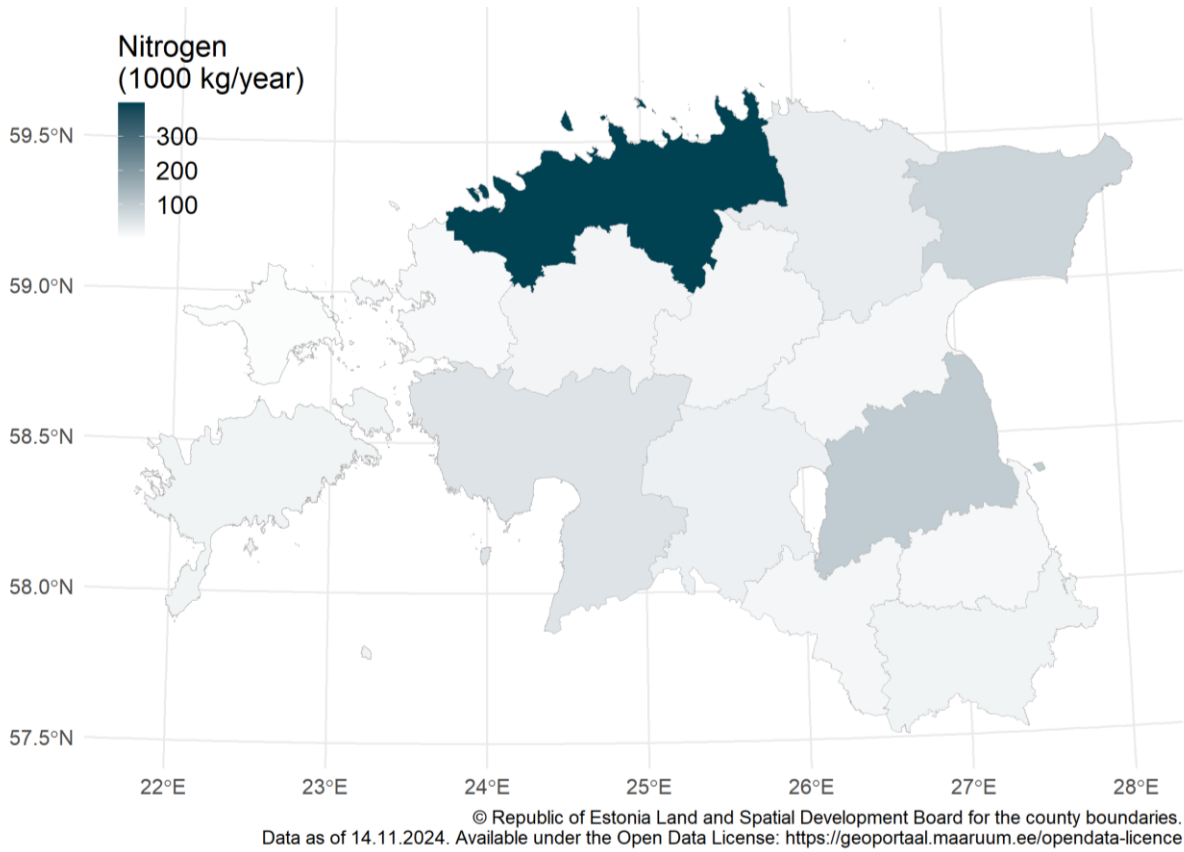
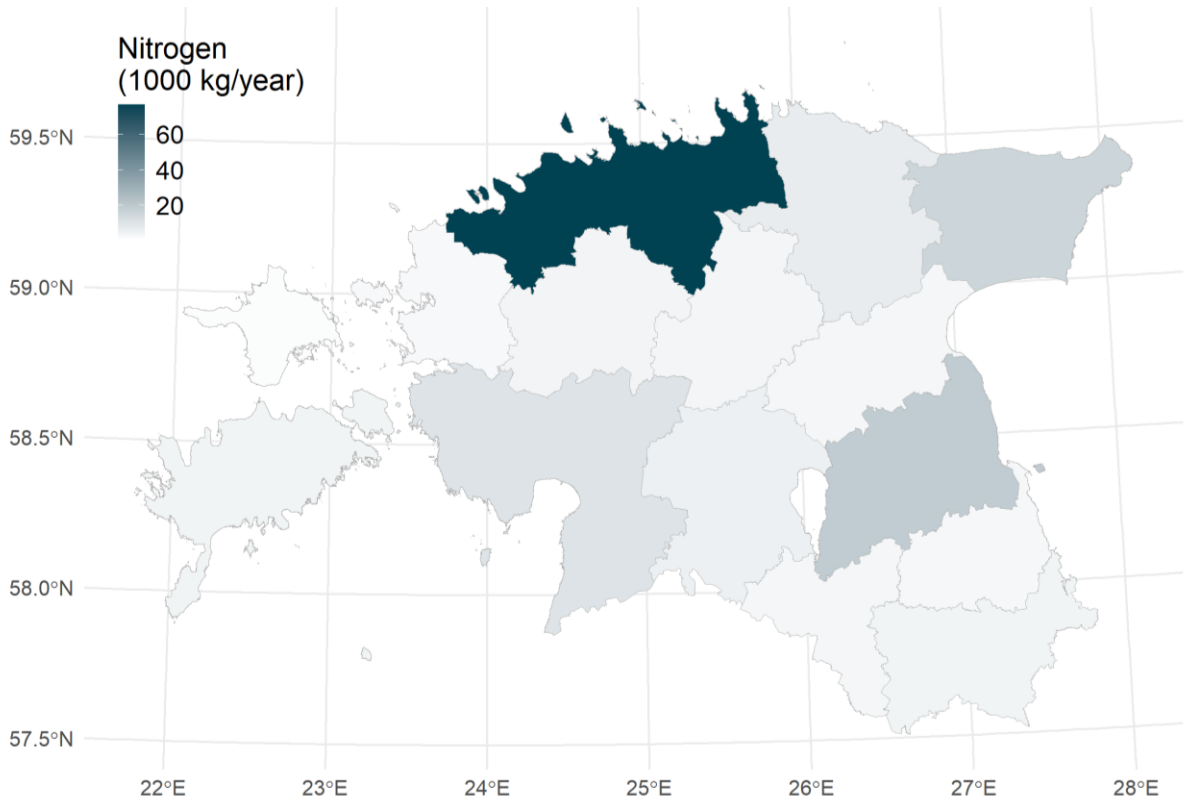
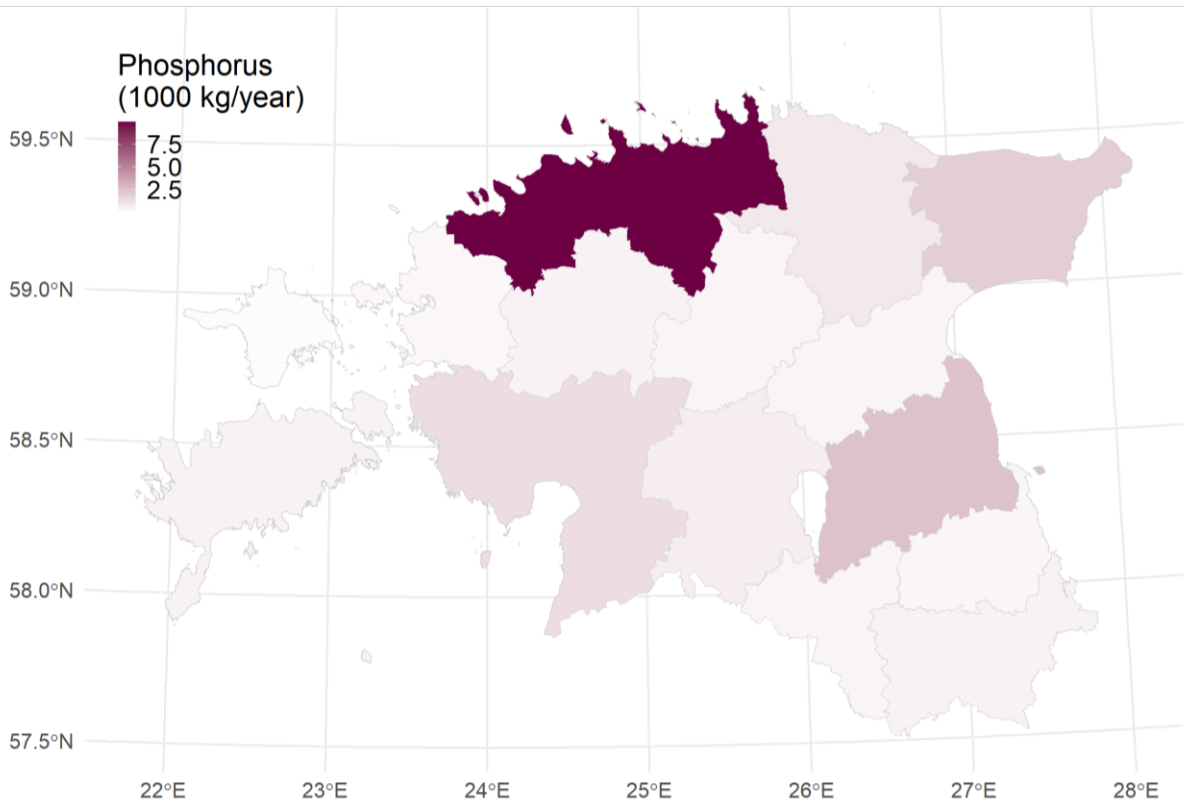


Figure 17. Spatial distribution of nitrogen (above) and phosphorus (below) in sewage sludge in Estonia.



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Figure 18. Spatial distribution of nitrogen (above) and phosphorus (below) in municipal bio-waste in Estonia.

Industrial side streams

The total masses and nutrient contents in animal by-products and food industry side streams are given in Tables 24 and 25, respectively. The results for animal by-products are available only as a total for all Estonia, while the food industry side streams are given county-specifically (Figure 19).

Table 24. Animal by-products in Estonia.

Region	NUTS_ID	Animal type	Animal by-products		
			Mass	Nitrogen	Phosphorus
			t/year	t/year	t/year
Estonia	EE00	Cattle	12 496	362.37	87.47
Estonia	EE00	Pigs	12 635	315.87	70.76
Estonia	EE00	Poultry	1 703	47.69	9.88
Estonia	EE00	Total	26 834	725.93	168.10

Table 25. Food industry side-streams in Estonia.

Region	NUTS_ID	Food industry side streams		
		Mass	Nitrogen	Phosphorus
		t/year	t/year	t/year
Estonia	EE00	78 296	531.13	165.59
Harju county	0037	19 272	219.38	65.35
Hiiu county	0039	0	0	0
Ida-Viru county	0045	4 950	18.72	3.30
Jõgeva county	0050	4 594	16.02	2.87
Järva county	0052	4 318	24.63	4.92
Lääne county	0056	0	0	0
Lääne-Viru county	0060	18 482	154.41	71.41
Põlva county	0064	106	0.38	0.11
Pärnu county	0068	72	2.28	0.18
Rapla county	0071	128	3.88	0.32
Saare county	0074	593	3.64	0.48
Tartu county	0079	19 303	61.39	11.54
Valga county	0081	422	5.73	1.53
Viljandi county	0084	5.04	0.04	0.02
Võru county	0087	6 050	20.64	3.57

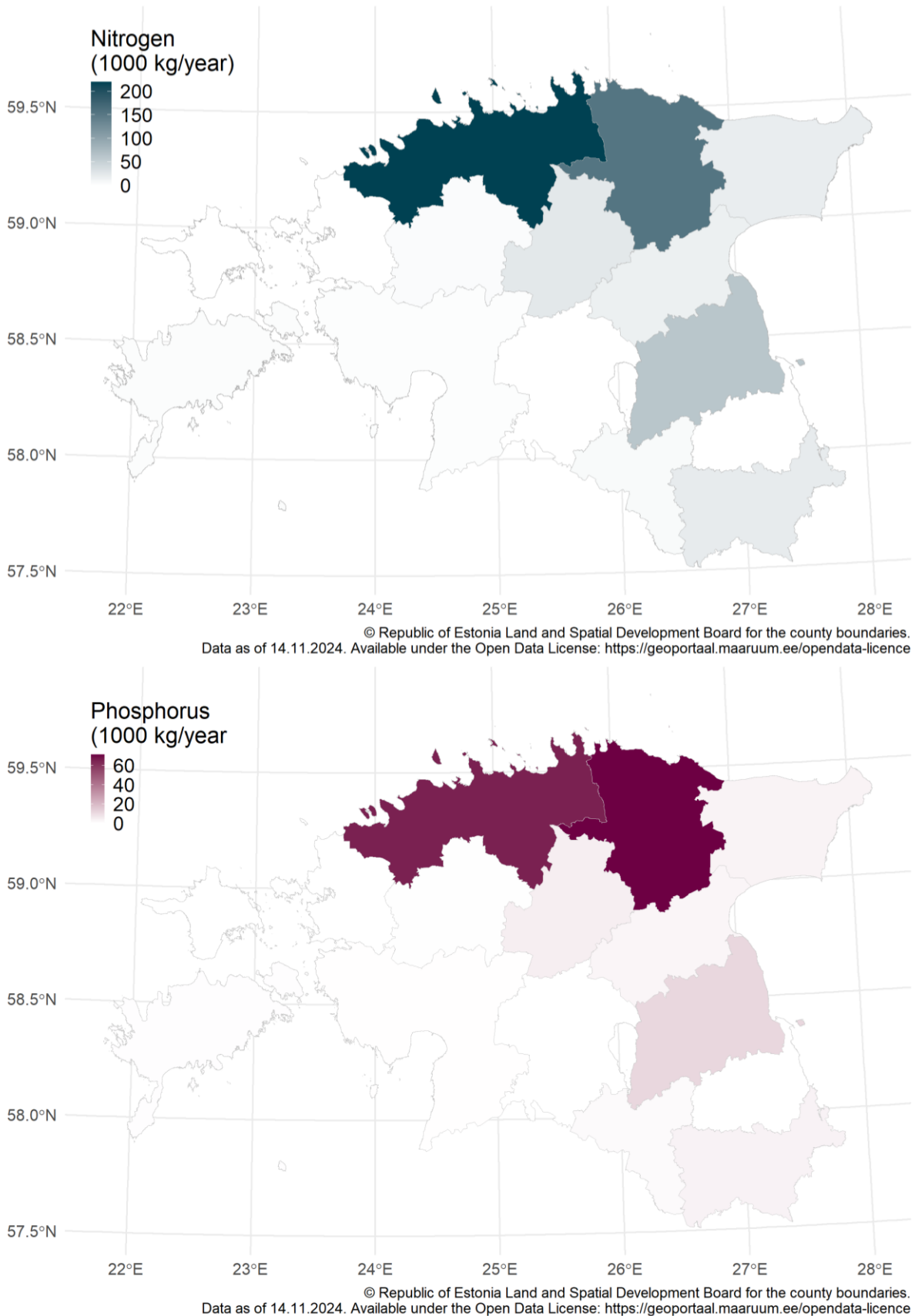


Figure 19. Spatial distribution of nitrogen (above) and phosphorus (below) in food industry side streams in Estonia.

When manure, sewage sludge and municipal biowaste are summed up, the spatial distribution of recyclable nitrogen and phosphorus in Estonia is shown in Figure 20.

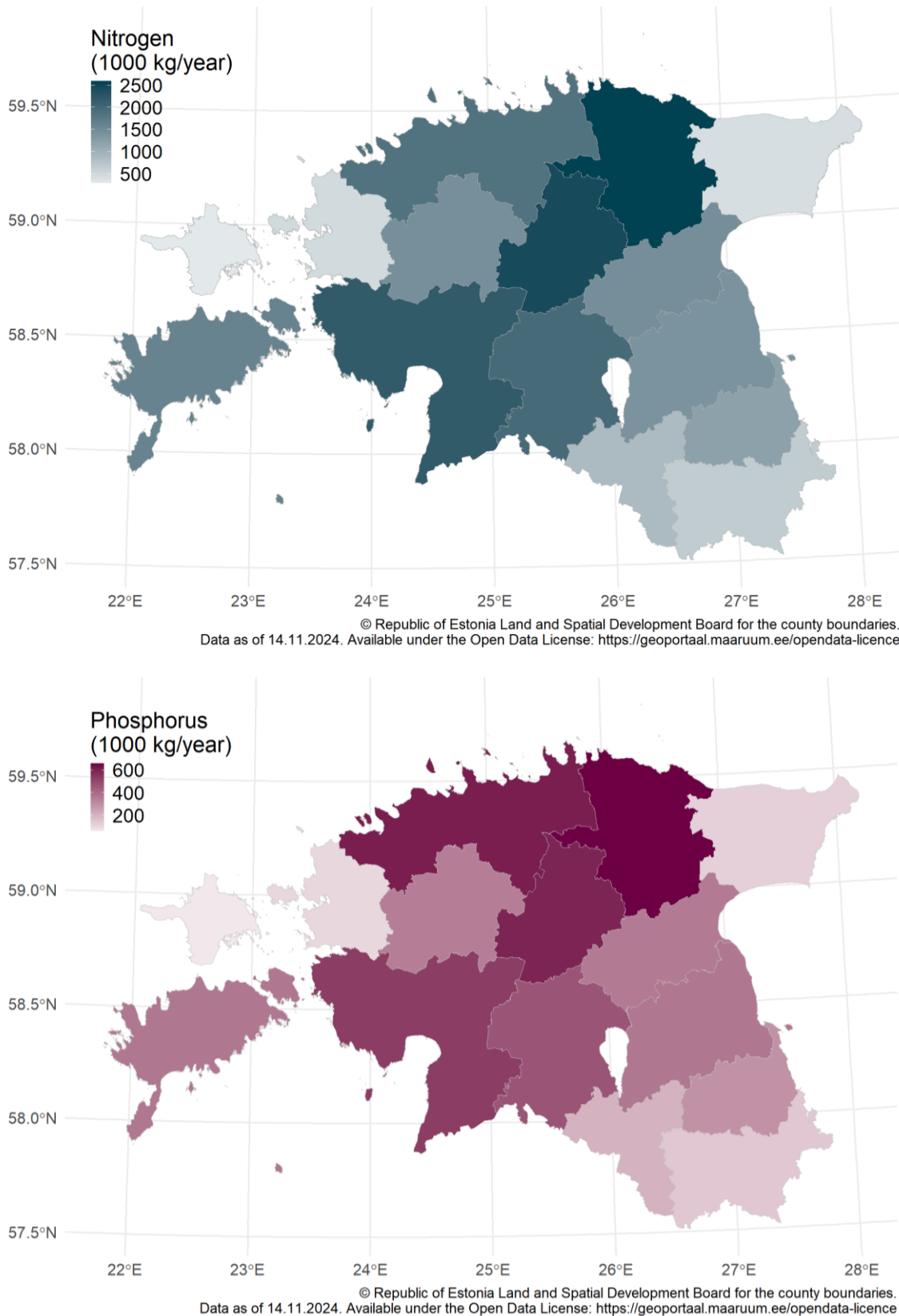


Figure 20. Spatial distribution of nitrogen (above) and phosphorus (below) in the recyclable manure, sewage sludge and municipal biowaste in total in Estonia.

Challenges with data availability for this report

The number of poultry (Table 12) is available only for the entire Estonia, not by county.

The results for animal by-products are available only as a total for all Estonia, while the food industry side streams are given county-specifically.

The amount of municipal source-sorted biowaste is calculated using the average production per capita in 2017/2018 (16 kg/person/year; Favoino & Giavini 2020) as no more recent data was available for Estonia.

It is difficult to find data on how the amount of manure is divided between liquid and solid manure. This has been found indirectly in this report based on the number of animal places and data on barn manure technologies, according to Kaasik (2020).

References

- Banks, C.J., Heaven, S., Zhang, Y. & Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018:12. https://www.ieabioenergy.com/wp-content/uploads/2018/12/Food-waste_WEB_END.pdf
- EC 2010. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part III: Project Interim Reports. https://ec.europa.eu/environment/archives/waste/sludge/pdf/part_iii_report.pdf
- Riigi Teataja, lisa 2, 2019. Looma väljaheidete keskmine kogus ja toiteelementide sisaldus loomakoha kohta. https://www.riigiteataja.ee/aktiiv/1011/0201/9011/MM_m73_lisa_2.pdf#
- Eurostat NUTS 2024. [The new NUTS 2024 classification is valid from 1 January 2024 and lists 92 regions at NUTS 1, 244 regions at NUTS 2 and 1 165 regions at NUTS 3 level. https://ec.europa.eu/eurostat/web/nuts](https://ec.europa.eu/eurostat/web/nuts)
- Eurostat, env_ww_spd. Sewage sludge production and disposal from urban wastewater (in dry substance (d.s)). Eurostat dataset on sewage sludge total production (env_ww_spd).
- Eurostat, apro_mt_pann. Slaughtering in slaughterhouses – annual data, 2023 https://ec.europa.eu/eurostat/databrowser/view/APRO_MT_PANN/default/table?lang=en
- Favoino, E. & Giavini, M. 2020. Bio-waste generation in the EU: Current capture levels and future potential- Bio-based Industries Consortium (BIC). 50 pp. https://zerowaste.europa.eu/wpcontent/uploads/2020/07/2020_07_06_bic_zwe_report_bio_waste_en.pdf
- Finnish Environment Institute 2000. Finnish Expert Report on Best Available Techniques in Slaughterhouses and Installations for the disposal or recycling of animal carcasses and animal waste. The Finnish Environment 539. 42 pp. <http://hdl.handle.net/10138/40549>
- Kaasik, A. 2020. Eesti lauda- ja sõnnikukäitlustehnoloogiate ning sõnniku laotamise tehnoloogiate uuring, 2020. <https://kliimaministeerium.ee/sites/default/files/documents/2021-07/eesti-lauda-ja-sonnikukaitlustehnoloogiate-ning-sonniku-laotamise-tehnoloogiate-uuring.pdf>

- Keskkonnaportaali. 2022. Keskkonnaportaali. Avalikud päringud. Jäätmed. https://tableau.en-vir.ee/views/Avalikud_pringud_Jtmed/Riigitasand?%3Aembed=y&%3Aiid=1&%3AisGuestRedirectFromVizportal=y
- Luostarinen, S., Laakso, J., Tampio, E., Skyttä, A. & Lehtonen, E. 2023. Ravinteiden kierrätyksen tilastointi ja seuranta : Ensimmäinen indikaattori ja kehittämissuhteet. Luonnonvara- ja biotalouden tutkimus 107/2023. Luonnonvarakeskus. Helsinki. 49 s. https://juri.luke.fi/bitstream/handle/10024/554105/luke-luobio_107_2023.pdf?sequence=1&isAllowed=y
- PRIA, cattle 2023. Number of cattle in Estonia, by counties and production groups in 31.12.2023. Agricultural Registers and Information Board in Estonia, 1.11.2024.
- PRIA, pigs 2023. Number of pigs in Estonia, by counties and production groups in 31.12.2023. Agricultural Registers and Information Board in Estonia, 4.11.2024.
- PRIA, horses 2024. Number of pigs in Estonia, by counties and production groups in 3.06.2024. Agricultural Registers and Information Board in Estonia, 3.06.2024.
- RT lisa3. Riigi Teataja, lisa 3, 2019. Eri tüüpi sõnniku summaarne kogus ja toiteelementide sisaldus pärast säilitamist loomade aasta ringi laudas pidamise korral. https://www.riigiteataja.ee/aktiivisa/1011/0201/9011/MM_m73_lisa_3.pdf#
- RT lisa4. Riigi Teataja, lisa 4, 2019. Eri tüüpi sõnniku summaarne kogus laudas ja toiteelementide sisaldus pärast säilitamist loomade perioodilise karjatamise korral. https://www.riigiteataja.ee/aktiivisa/1011/0201/9011/MM_m73_lisa_4.pdf#
- RT KKM_m65_lisa. Keskkonnaministri 14.12.2015. a määrus nr 70 „Jäätmete liigitamise kord ja jäätmenimistu“. https://www.riigiteataja.ee/aktiivisa/1181/2202/0026/KKM_m65_lisa.pdf#
- Statistics Estonia a. RV0222U: RAHVASTIK, 1. JAANUAR, 2024. | Aasta, Sugu, Maakond ning Rahvus - https://andmed.stat.ee/et/stat/rahvastik_rahvastikunaitajad-ja-koosseis_rahvaarv-ja-rahvastiku-koosseis/RV0222U/table/tableViewLayout2
- Statistics Estonia b. Statistics Estonia classifiers, 2024. <https://klassifikatorid.stat.ee/item/stat.ee/6b00ba71-d70a-469d-a291-c443c9edc4f1/7>
- Statistics Estonia c. Estonia Statistics, animals and birds by county, 2023. Eesti Statistika, loomad ja linnud maakonna järgi (kvartalid). https://andmed.stat.ee/et/stat/majandus_pellumajandus_pellumajandussaaduste-tootmine_loomakasvatussaaduste-tootmine/PM09
- Wikimedia Commons 2005 .The map of counties of [Estonia \(File:Estonia counties nov2005.png - Wikimedia Commons, GNU Free Documentation License\)](#)

3.3. Latvia

Zanda Melnalksne & Iveta Grudovska, Farmers' Parliament (ZSA)

Latvia is situated in the Northern Europe (Baltic Sea Region) borders with Lithuania to the North, Estonia to the East, Poland to the South. The Baltic Sea borders Western and The Gulf of Riga borders central parts of Latvia. Total area of country is approximately 64 589 square kilometres and the population around 1.9 million people. Key economic sectors of the country are agriculture (a major contributor, focus on crops such as grain), forestry (main product: wood pulp), manufacturing (machinery, vehicles, chemicals), and services especially with the growing sectors of tourism and financial services.

An attempt to assess the nutrient recycling potential in Latvia is made for the entire territory of Latvia (classified as a NUTS 2 region; Table 26).

Table 26. Classification of NUTS regions in Latvia.

Kods	NUTS 1	NUTS 2	NUTS 3
LV			
LV0	Latvija		
LV00		Latvija	
LV005			Latgale
LV009			Zemgale
LV00A			Rīga
LV00B			Kurzeme
LV00C			Vidzeme

3.3.1. Nutrient recycling potential in Latvia

There is no general data collection focusing on production side streams and their nutrients available in Latvia. Therefore, to obtain the necessary data for this report, different data sources and collection methods were applied. The following Latvian official institutions were consulted both through physical communication and via their available databases and reports:

- Ministry of Agriculture Republic of Latvia;
- State Plant Protection Service (VAAD);
- Latvia's Farm Data Centre (reorganized from 01.01.2025);
- Rural Support Service;
- Food and Veterinary Service;
- The Central Statistical Bureau of Latvia (CSB);
- Public waste databases of the SLLC "Latvian Environment, Geology and Meteorology Centre (LEGMC)";
- Reports of the studies on biowaste materials in Latvia.

Pieces of necessary data were found and are reported here. However, a comprehensive calculation could not presently be conducted.

Livestock Manure

Several institutions in Latvia are involved in collecting data on manure production and management. However, publicly available information differs, apparently due to different methodological approaches and accuracy of the data. After evaluation of the available data and their collection methodologies, information available from the CSB is used in this report.

The number of livestock is available in CBS (2024) for the year 2023 (Table 27).

Table 27. Number of livestock in Latvia in 2023 (CBS 2024).

Animal category	Number of animals
Cattle	368 100
of which	
calves under 1 year	100 500
young cattle, 1-2 years	59 700
cattle over 2 years	207 800
of which dairy cows	119 000
Pigs	290 000
of which	
piglets under 20 kg	52 800
piglets 20-50 kg	90 200
young breeding sows	15 100
breeding sows	21 200
fattening pigs	110 400
Sheep	78 300
of which ewes	50 000
Goats	10 300
Horses	9 000
Poultry	5 922 300
of which	
Laying hens	3 385 000

The amount of manure applied on field soil is also given in the official statistics (CBS 2024) as part of all organic fertiliser use (Table 28). When summing up solid manure, slurry, poultry manure and urine, the total amount of manure in 2023 is 2 581 900 tons. According to the national nutrient balances for nitrogen and phosphorus, 30 750 tons of nitrogen and 7 426 tons of phosphorus were applied on field soils in 2022 (Table 29).

Table 28. Use of organic fertilizers in Latvia (CBS 2024).

Year	2020	2022	2023
Total (thousand tons)	4 577.8	4 486.3	4 234.2
of which:			
Solid manure	1 857.6	1 820.4	1 508.5
Slurry (excl. poultry)	1 003.1	924.4	878.1
Poultry manure	40.7	40.2	41.4
Compost	21	45.1	51.6
Urine	186.9	180.7	153.9
Straw (post-harvest residues)	582.7	641.5	738.8
Digestate	853.3	820.1	851.1
Other	32.5	13.9	10.9

Table 29. The national nutrient balances offer data on nitrogen and phosphorus applied on field soils in Latvia (CBS 2024).

	2020	2021	2022
Gross nitrogen input	32 433	32 077	30 750
cattle	23 585	23 113	22 189
pig	3 348	3 606	3 358
sheep and goat	1 588	1 562	1 521
poultry	2 550	2 529	2 505
other livestock	1 362	1 267	1 178
Gross phosphorus input	7 568	7 527	7 426
cattle	4 155	4 068	4 086
pig	812	874	812
sheep and goat	362	357	347
poultry	1 957	1 967	1 928
other livestock	282	261	254

Municipal waste streams

Sewage sludge

Data on sewage sludge is reported by Latvian wastewater treatment companies yearly and stored in the database of the LEGMC "Latvian Environment, Geology and Meteorology Centre (LEGMC)". The amount of sewage sludge in tons of dry matter is derived directly from this database (Table 30).

Table 30. Quantities of sewage sludge given in the t/year according to the dry matter in Latvia (LEGMC).

	Amount of sewage sludge produced	Processed amount of sludge (biogas, compost)
Total amount in Latvia, 2023	20 768	15 048
Total amount in Latvia, 2022	20 047	14 778

According to the Latvian Water and Wastewater Works Association (Zviedris et al. 2021), a ton of dry matter in Latvian sewage sludge contains 25 kg of phosphorus, 63 kg of nitrogen, and 720 kg of organic matter. When multiplied with the total amount of sewage sludge produced (Table 9), this amounts to 519 tons of phosphorus and 1308 tons of nitrogen in 2023.

Municipal biowaste

In Latvia, the system of collecting source-separated biowaste was introduced only in 2024. Therefore, exact data on municipal source-separated biowaste is not yet available. Based on the European Commission Delegated Decision (EU) 2019/1597, a general methodology has been established, according to which in Latvia, starting from 2020, measurements are carried out at least once every four years to determine the volume of food waste and surplus at each stage of the food supply chain - primary production, processing and manufacturing, retail and other distribution, food service, and households. Still, estimates of the amounts produced by households and other sectors have been made already previously.

According to Latvian Waste Management Association, a significant amount of food waste is generated by primary production (agriculture), retail, catering and households (Table 31). Food waste from food retail and other distribution channels is assessed at 48 372 t in 2019 and 47 853 t in 2020. The restaurant and catering services are estimated to produce 13 993 t of food waste in 2019, decreasing to 10 627 t in 2020. The assessment of the amount of food waste in households was based on survey data. In 2019, 38 205 t and in 2020 37 880 t of bio-waste were processed by the households themselves (composting or feeding pets). At the same time, most of the food waste produced in households was not separated but collected with landfilled mixed waste. The estimated amounts were 119 668 t in 2019 and 118 649 t in 2020. Altogether this means 157 873 t of household food waste in 2019 and 156 528 t in 2020.

Table 31. Municipal biowaste in Latvia.

	Produced biowaste amount, t		Processed biowaste amount, t		Biowaste amount available for recovery, t	
	2019	2020	2019	2020	2019	2020
Food processing sector food waste	53 483	66 107	50 293	61 888	3 190	4 219
Retail sector food waste	48 372	47 853	n/a	n/a	48 372	47 853
Catering services food waste	13 993	10 627	n/a	n/a	13 993	10 627
Household food waste	157 873	156 628	38 205	37 880	119 668	118 748
Total, t	273 721	281 215			185 223	181 447

Data source: Report “Measurements for Determining the Volume of Food Waste and Surpluses”

The amount of nitrogen and phosphorus in these fractions was not calculated.

Industrial side streams

Animal by-products

The Central Statistics Bureau of Latvia provides data on slaughtered livestock, which could be as the source information for recalculation of the animal by-products. Table 32 describes amounts of slaughtered animal in last years. The share of animal by-products and their nutrient contents based on this data was not calculated presently.

Table 32. Number of slaughtered animals in Latvia (CBS 2024).

Animal groups	2023	2024
Cattle totally	72 635	66 198
bulls	12 853	11 731
cows	37 658	34 604
heifers	10 503	9 737
calves till 8 month.	8 908	7 693
calves 8–12 month.	2 713	2 433
Pigs	386 871	394 226
Sheep	26 254	25 570
Goat	548	766
Poultry, thousands	21 769	21 968

Food industry side streams

Food industry companies send most of their food waste for further processing, and only a small part ends up in unsorted waste containers (Table 33). In 2019, 50 293 t of food industry side streams were sent for recycling, while 3 190 t was not source-separated. Similarly in 2020, 61 888 t were sent for recycling and 4 219 t remained unsorted.

Table 33. Food industry side streams in Latvia.

	Produced biowaste, t		Processed biowaste, t		Biowaste available for recovery, t	
	2019	2020	2019	2020	2019	2020
Food processing side streams	53 483	66 107	50 293	61 888	3 190	4 219

References

CBS 2024. Agriculture of Latvia – Collection of Statistics. Central Statistical Bureau of Latvia. https://admin.stat.gov.lv/system/files/publication/2024-06/Nr_16_Latvijas_Lauksaimnieciba_2024_%2824_00%29_LV_EN_0.pdf

LEGMC. Wastewater data. Latvian Environment, Geology and Meteorology Centre. <https://videscentrs.lvgmc.lv/lapas/wastewater>

Zviedris, J., Jansons, J., Kazimiraitis, A. Vītoliņš, R., Grīntāle, D. & Dejus, S. 2021. Esošās situācijas izvērtējums par notekūdeņu dūņu apjomu, kvalitāti, pārstrādi un izmantošanu Latvijā, biedrība Latvijas Ūdensapgādes un kanalizācijas uzņēmumu asociācija. LIFE Good-Water IP projekta nodevums, Rīga.

3.4. Lithuania

Edmundas Akstinas, Green Circle LT

Data on available waste side streams and nutrient potential in Lithuania is vague and scattered. Therefore, the data was gathered in contact with numerous institutions and by analysing separate databases. The recyclable biomasses presented here are livestock manure and animal by-products. Part of the manure data is available regionally for Lithuania (Figure 21).



Figure 21. The division of Lithuania into regions (Wikipedia 2025).

3.4.1. Nutrient recycling potential in Lithuania

Livestock manure

To calculate manure nutrient potential, the number of livestock units per Lithuanian region was obtained. Using the German coefficients also applied in the Eurostat-method (See. Chapter 2), the available potential nutrients in Lithuania were calculated (Table 34). From the data, cattle production is quite evenly spread across the country, while pig production is concentrated especially to Panevėžys and Šiauliai regions in the North and poultry production to Vilnius, Alytus, Kaunas and Panevėžys regions in Central, South and North Lithuania.

Table 34. Number of animals and the nutrient content in livestock manure in Lithuania.

Cattle, 2024	Units	Nitrogen, t/y	Phosphorus, t/y
Vilnius region	26 874	1 694	247
Alytus region	36 827	2 322	338
Kaunas region	67 392	4 249	619
Klaipėda region	79 385	5 005	730
Marijampolė region	59 146	3 729	544
Panevėžys region	66 648	4 202	612
Šiauliai region	78 677	4 961	723
Tauragė region	95 623	6 029	879
Telšiai region	68 784	4 337	632
Utena region	44 166	2 785	406
Lithuania	623 522	39 313	5 730
Pigs, 2024	Units	Nitrogen, t/y	Phosphorus, t/y
Vilnius region	35 978	399	68
Alytus region	2 198	24	4
Kaunas region	50 705	563	96
Klaipėda region	21 254	236	40
Marijampolė region	39 663	440	75
Panevėžys region	104 195	1 157	197
Šiauliai region	123 342	1 369	233
Tauragė region	50 033	555	95
Telšiai region	16 708	185	32
Utena region	53 015	588	100
Lithuania	497 091	5 518	940
Poultry, 2024	Units	Nitrogen, t/y	Phosphorus, t/y
Vilnius region	2 220 029	1 199	266
Alytus region	1 532 465	828	184
Kaunas region	2 878 692	1 554	345
Klaipėda region	732 447	396	88
Marijampolė region	372 906	201	45
Panevėžys region	1 077 686	582	129
Šiauliai region	492 273	266	59
Tauragė region	211 175	114	25
Telšiai region	713 600	385	86
Utena region	424 043	229	51
Lithuania	10 655 316	5 754	1 279
Sheep, goats	Units	Nitrogen, t/y	Phosphorus, t/y
Lithuania	141 860	2 447	310

The amount of manure nitrogen and phosphorus for cattle, pigs and poultry in total is presented in Table 34 and their spatial distribution over the Lithuanian regions in Figure 22.

Table 35. Total manure nitrogen and phosphorus content in Lithuania (cattle, pigs and poultry).

Region	Nitrogen, t/y	Phosphorus, t/y
Vilnius region	3 292	581
Alytus region	3 174	526
Kaunas region	6 366	1 060
Klaipėda region	5 637	858
Marijampolė region	4 370	664
Panevėžys region	5 941	938
Šiauliai region	6 596	1 015
Tauragė region	6 698	999
Telšiai region	4 907	750
Utena region	3 602	557
Lithuania	50 583	7 948

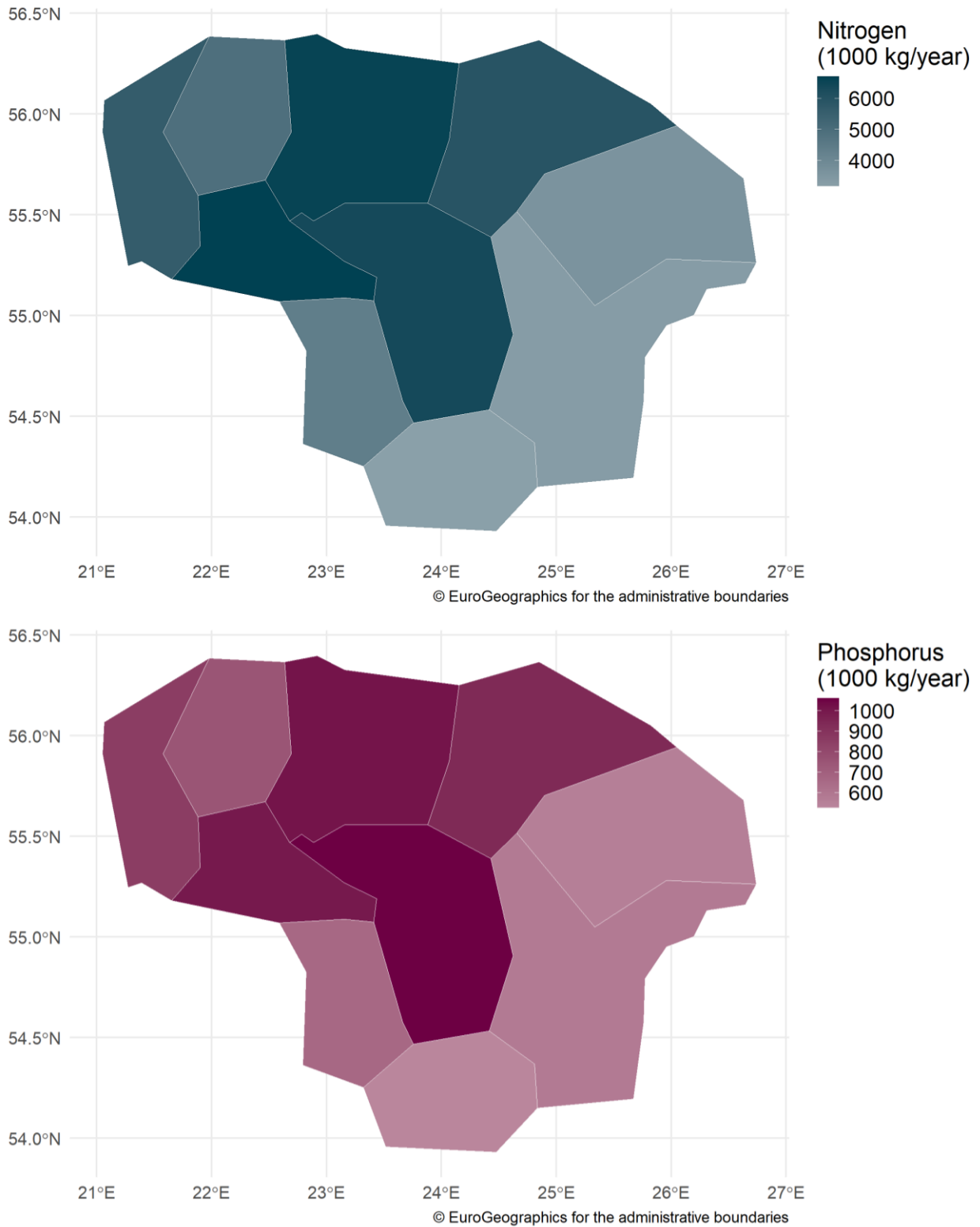


Figure 22. Spatial distribution of manure (cattle, pigs and poultry) nitrogen (above) and phosphorus (below) in Lithuania in 2024.

Industrial side streams

The amount and nutrient content of animal by-products produced in Lithuania were estimated via slaughtering data for the whole country and the coefficients for animal by-products used in the Eurostat-method (see: Chapter 2; Table 36).

Table 36. The amount of animal-products and their nutrient in Lithuania in 2023.

Slaughtered animals, 2023	Heads	Animal by-products, t/y	Nitrogen t/y	Phosphorus t/y
Cattle	301 887	54 340	1 576	380
Pigs	775 663	20 167	504	113
Poultry	45 233 564	34 830	975	202
Total	46 311 114	109 337	3 055	695

References

Ministry of Agriculture of the Republic of Lithuania: <https://www.zum.lrv.lt/lt/>

Ministry of Environment of the Republic of Lithuania: <https://www.am.lrv.lt/lt/>

Lithuanian Centre for Agricultural and Forestry Sciences: <https://www.lammc.lt/lt>

State Enterprise Agricultural Data Centre: <https://www.zudc.lt/>

State Data Agency: <https://www.osp.stat.gov.lt/>

Description of Environmental Requirements for Manure and Slurry Management, approved by Order No. 14 of the Minister of Environment of the Republic of Lithuania and the Minister of Agriculture of the Republic of Lithuania of 14 July 2005. D1-367/3D-342 (with the latest amendments) "On the approval of the description of environmental requirements for manure and slurry management": <https://www.e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.260167/asr>

Rules and advice on smart farming: https://www.zum.lrv.lt/uploads/zum/documents/files/-LT_versija/Veiklos_sritys/Maisto_sauga_ir_kokybe/Nitratu_direktyvos_igyvendinimas/-PUTP_leidiny_2007.pdf

Order No. 19 of the Minister of Agriculture of the Republic of Lithuania and the Minister of the Environment of the Republic of Lithuania of 19 December 2001 452/607 "On the Approval of the Requirements for the Protection of Waters from Pollution by Nitrogen Compounds from Agricultural Sources."

Law of the Republic of Lithuania on Water.

The "Programme for the Reduction of Water Pollution from Agricultural Sources" approved by Order No. 3D-686/D1-676 of the Minister of Agriculture of the Republic of Lithuania and the Minister of the Environment of the Republic of Lithuania of 9 December 2008.

"Determination of the Content of Nitrogen and Phosphorus in Manure and Slurry of Cattle, Pigs, Poultry (Meat and Laying Hens), Sheep, Goats" Final Report.

3.5. Poland

Damian Wach, Krystian Mocny, Piotr Skowron & Magdalena Borzęcka, Institute of Soil Science and Plant Cultivation (IUNG)

Poland's environmental policy is a key element of its environmental protection strategy, both at national and international level. Since joining the European Union in 2004, Poland has been implementing numerous programmes and initiatives to improve waste management. The country adapts environmental protection measures to specific local needs, considering differences in population density, urbanization and industrial activity. For example, the mazowieckie voivodeship (PL92) generates significant amounts of municipal waste, while the śląskie voivodeship (PL22) dominates the production of industrial waste (Figure 23). Poland actively participates in international environmental protection programmes, cooperating with other EU countries and implementing the UN Sustainable Development Goals. Regional environmental programmes enable actions to be better tailored to local needs, which contributes to achieving ambitious recycling and sustainable development goals at national and international level.



Figure 23. Administrative divisions of Poland.

3.5.1. Materials and methods

Livestock manure

For calculating the quantity and characteristics of livestock manure, the database provided by ARMA (Agency for the Restructuring and Modernisation of Agriculture) is used. The database contains information for 2023 on farms, where cattle (categorised by sex and age), pigs and poultry (laying hens, broilers, ducks, geese, turkeys) were housed, together with the number of animals and the housing system. In the case of pigs, these are active herd sites, where at least one event has been reported in a 12-month period. The database was created based on

notifications submitted by livestock owners at ARMA offices or in electronic forms sent directly to the database.

Only animals kept in a closed system are selected for weight calculations. The proportion of manure left on pasture by grazing animals is also excluded from the calculations. The amount of manure per animal was obtained by multiplying the manure production coefficients for different technological groups of animals (Nitrate Program, 2023; Phosphorus Program, 2023). The coefficients used are derived from the Nitrate Programme, which is legally obligatory for all farms in Poland. Information on manure properties concerning nitrogen and phosphorus is calculated based on data on the content of these elements in natural fertilisers for individual technological groups of animals. In the case of nitrogen, information from the Nitrogen Programme was used (Nitrate Program, 2023). In the case of phosphorus, data from the Fertilizer and Nutrient Balance Advisory System (INTER-NAW Advisory System) and Phosphorus Program, which is recommended by the Polish government for farmers and producers, were used (Phosphorus Program 2023).

Municipal and industrial wastes

Sewage sludge

The quantity of municipal sewage sludge and its properties concerning nitrogen and phosphorus content are estimated based on data shared by the National Statistics for the year 2022. Sewage sludge refers to sludge from digesters and other wastewater treatment facilities. They are mostly obtained from the treatment of wastewater from both households and industry. Available data provide information on the sludge dry matter content by the voivodeships (National Statistics, 2023). To estimate the nitrogen and phosphorus content of the sludge, guidelines from the literature are used (EC 2010). The estimation consists of multiplying the weight of the sludge by the values of the nutrients specified, i.e. 3.85% of DM for nitrogen and 2.6% of DM for phosphorus.

Municipal biowaste and industrial side streams (food industry side streams, animal by-products)

The amount of municipal source-separated biowaste and industrial side streams (animal by-products, food industry side streams) are estimated using data from BDO (Waste Database). The data made available is aggregated from reports obtained from waste generators and waste managers, including a list of waste generators and waste processors for the period of 2020-2021. Data on the amount of municipal waste and its nitrogen and phosphorus content are compiled at NUTS-2 level. The waste is divided into different categories with assigned waste codes. The weight of municipal waste was calculated based on waste codes 20 01 08 and 20 02 01 (Table 35). The weight of industrial waste was calculated based on the waste classified as animal by-products and by-products of the food industry. The codes assigned to each waste type are shown in Table 37.

To estimate the nitrogen and phosphorus content of municipal biowaste, guidelines from the literature were used (Banks et al. 2018). The values taken from the literature for estimating the content of waste properties are: 0.74% of fresh mass for nitrogen and 0.4% of fresh mass for phosphorus. For the estimation of nitrogen and phosphorus content in industrial waste, the guidelines from the literature were used (Timonen et al. 2019). The values taken from the literature for estimating the content of industrial by-product waste properties are: 8 g of nitrogen per kilogram of fresh waste mass and 1 g of phosphorus per kilogram of fresh waste mass.

Table 37. Codes and groups of different types of waste in Poland.

Code	Waste type	Waste group
02 01 01	Deposits from washing and cleaning	Animal by-products
02 01 02	Waste animal tissue	Animal by-products
02 01 03	Waste plant matter	Food industry side-streams
02 01 06	Animal excrement	Animal by-products
02 01 81	Dead animals and animal tissue waste constituting specific and high risk material other than those mentioned in 02 01 80	Animal by-products
02 01 82	Animals that died and were slaughtered out of necessity	Animal by-products
02 01 83	Waste from hydroponics	Food industry side-streams
02 02 01	Waste from washing and preparing raw materials	Animal by-products
02 02 02	Waste animal tissue	Animal by-products
02 02 03	Raw materials and products not suitable for consumption or processing	Animal by-products
02 02 04	Sediments from industrial sewage treatment plants	Animal by-products
02 02 82	Wastes from fish meal production other than those mentioned in 02 02 80	Animal by-products
02 03 01	Sludges from washing, cleaning, peeling, centrifuging and separation of raw materials	Food industry side-streams
02 03 03	Post-extraction waste	Food industry side-streams
02 03 04	Raw materials and products not suitable for consumption or processing	Food industry side-streams
02 03 05	Sediments from industrial sewage treatment plants	Food industry side-streams
02 03 80	Bagasse, sludge and other waste from processing plant products (excluding 02 03 81)	Food industry side-streams
02 03 81	Waste from plant feed production	Food industry side-streams
02 03 82	Tobacco waste	Food industry side-streams
02 04 01	Sediments from cleaning and washing beets	Food industry side-streams
02 04 02	Non-standard calcium carbonate and sugar chalk (defecation lime)	Food industry side-streams
02 04 03	Sediments from industrial sewage treatment plants	Food industry side-streams
02 04 80	Sweet	Food industry side-streams
02 05 01	Raw materials and products unsuitable for consumption or processing	Food industry side-streams
02 05 02	Sediments from industrial sewage treatment plants	Food industry side-streams
02 05 80	Waste whey	Food industry side-streams
02 06 01	Raw materials and products unsuitable for consumption and processing	Food industry side-streams
02 06 03	Sediments from industrial sewage treatment plants	Food industry side-streams
02 06 80	Unusable food fats	Food industry side-streams
02 07 01	Waste from washing, cleaning and mechanical grinding of raw materials	Food industry side-streams
02 07 02	Waste from spirit distillation	Food industry side-streams
02 07 04	Raw materials and products not suitable for consumption or processing	Food industry side-streams
02 07 05	Sediments from industrial sewage treatment plants	Food industry side-streams
02 07 80	Pomace, must and fermentation sediments, decoctions	Food industry side-streams
04 01 01	Fleshing waste (fleshings and calcium splits)	Animal by-products
04 01 02	Liming waste	Animal by-products
04 01 07	Chromium-free sludge, especially from industrial sewage treatment plants	Animal by-products
04 01 09	Waste from polishing and finishing	Animal by-products
20 01 08	Biodegradable kitchen waste	Municipal source-separated biowaste
20 02 01	Biodegradable waste	Municipal source-separated biowaste

3.5.2. Nutrient recycling potential in Poland

Poland hosts a significant potential for nutrient recycling (Table 38).

Table 38. The amount and nutrient content of different recyclable biomasses in Poland.

	Mass (t/a)	Ntot (t/a)	Ptot (t/a)
Livestock manure	116 774 638	508 034	96 515
Municipal biowaste	3 596 741.3	26 615.9	3 452.9
Sewage sludge	580 800.0	22 360.8	15 100.8
Animal by-products	1 462 175.3	40 940.9	8 963.1
Industrial side streams	5 001 444.3	40 011.6	5 001.4
Total	116 774 638	508 034	96 515

Livestock manure

Livestock manure represents the largest recyclable biomass in Poland. At country level, the annual total mass of manure from cattle, pigs and poultry amounts to 116 774 638.3 tonnes, of which 508 033.8 tonnes is nitrogen and 96 515.1 tonnes is phosphorus. The largest amounts of manure are found in the wielkopolskie region (NUTS PL41), where the annual mass of manure from cattle, pigs and poultry reaches 23 385 527.8 tonnes, of which 110 266.6 tonnes is nitrogen and 20 200.6 tonnes is phosphorus. In contrast, the least manure is found in the podkarpackie region (NUTS PL82), with an annual mass of 1 393 257.0 tonnes, including 5 498.3 tonnes of nitrogen and 1 149.3 tonnes of phosphorus. Detailed information on each region is provided in Table 39 and the spatial distribution of manure nutrients is presented in Figure 24.

Table 39. The amount and nutrient content in manures in Poland in 2023.

NUTS_id	Region	Mass (t/a)	Nitrogen (t/a)	Phosphorus (t/a)
PL21	małopolskie	2 482 066.71	9 385.87	1 895.70
PL22	śląskie	2 589 453.98	12 226.50	2 198.20
PL41	wielkopolskie	23 385 527.83	110 266.64	20 200.64
PL42	zachodniopomorskie	2 610 046.71	15 584.05	2 585.75
PL43	lubuskie	1 635 530.90	11 858.26	1 511.01
PL51	dolnośląskie	1 799 653.93	9 313.50	1 545.70
PL52	opolskie	3 035 649.35	12 674.91	2 684.04
PL61	kujawsko-pomorskie	9 288 578.01	34 163.05	7 690.38
PL62	warmińsko-mazurskie	8 205 689.99	34 597.76	6 627.61
PL63	pomorskie	4 973 363.14	19 225.15	4 338.86
PL71	łódzkie	9 010 934.70	35 961.20	7 698.06
PL72	świętokrzyskie	2 359 986.73	9 740.32	1 907.88
PL81	lubelskie	5 875 587.32	24 677.67	4 725.57
PL82	podkarpackie	1 393 257.04	5 498.29	1 149.28
PL84	podlaskie	15 930 702.55	55 534.35	11 467.17
PL92	mazowieckie	22 198 609.39	107 326.29	18 289.20
	Poland	116 774 638.3	508 033.8	96 515.1

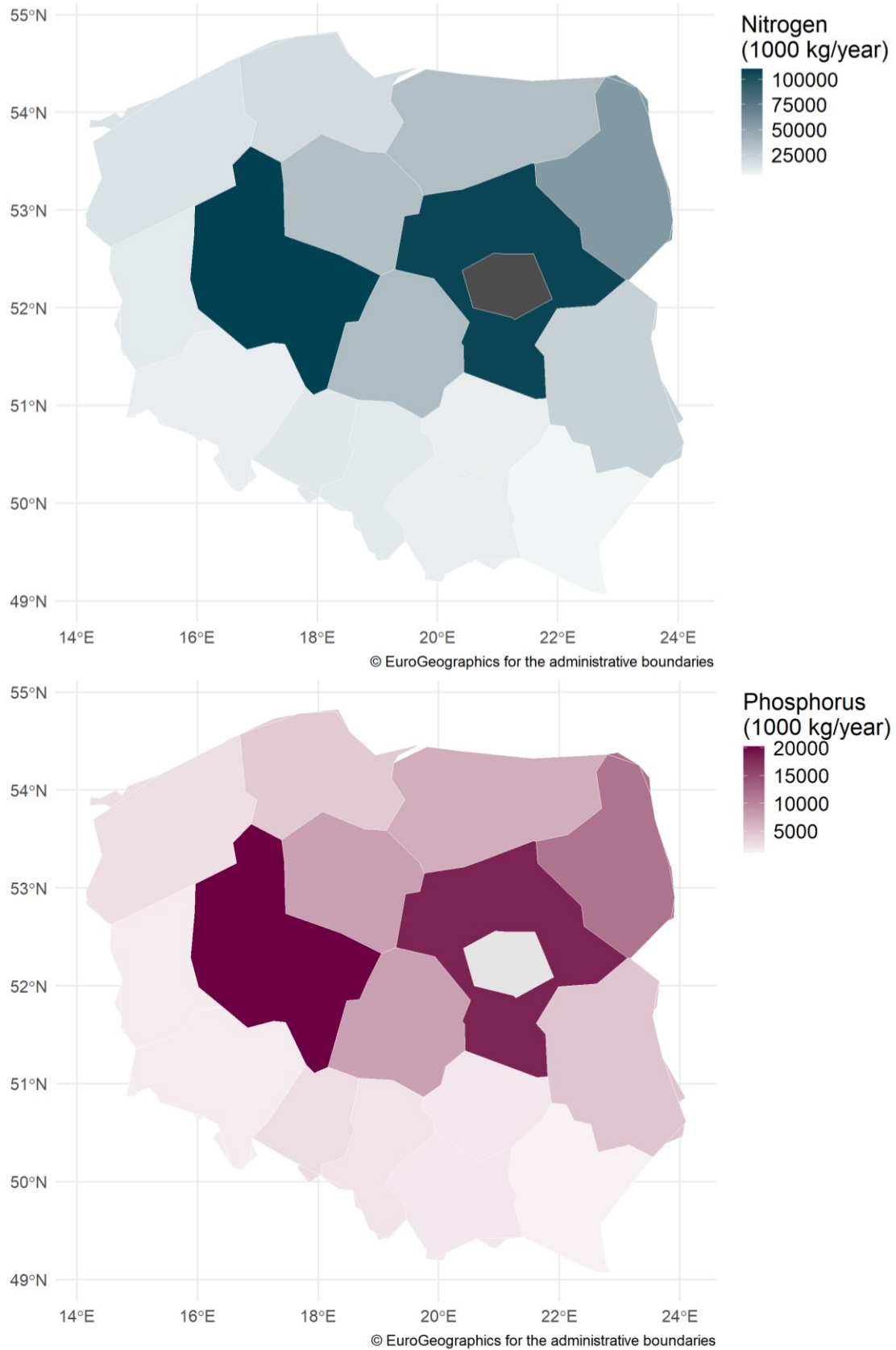


Figure 24. Spatial distribution of nitrogen (above) and phosphorus (below) in livestock manure in Poland in 2023 (cattle, pigs and poultry).

Solid cattle manure in Poland reaches an annual mass of 48 583 753.0 tons, containing 153 624.4 tons of nitrogen and 51 837.6 tons of phosphorus. The largest amount of cattle

manure in this form occurs in the mazowieckie region (NUTS PL92), where its annual mass is 9 841 796.0 tons, including 31 428.3 tons of nitrogen and 10 483.4 tons of phosphorus. On the other hand, the smallest amounts of solid cattle manure are found in the lubuskie region (NUTS PL43), where this mass is 506 796.5 tons, containing 1 127.3 tons of nitrogen and 30.4 tons of phosphorus. Separately collected urine in Poland amounts to 32 683 411.2 tons per year, containing 101 646.5 tons of nitrogen and 2 782.4 tons of phosphorus. The mazowieckie region (NUTS PL92) has the most urine, with an annual mass of 6 383 814.9 tons, including 19 934.6 tons of nitrogen and 545.0 tons of phosphorus. In turn, the smallest amounts of urine occurred in the lubuskie region (NUTS PL43), where its mass was 361 308.8 tons, containing 1 127.3 tons of nitrogen and 30.4 tons of phosphorus. Slurry on a national scale reaches an annual mass of 159 832.6 tons, containing 587.6 tons of nitrogen and 113.5 tons of phosphorus. The largest amount of slurry was found in the wielkopolskie region (NUTS PL41), where the annual mass was 48 081.7 tons, containing 173.8 tons of nitrogen and 32.1 tons of phosphorus. The smallest amounts of slurry were found in the zachodniopomorskie region (NUTS PL42), where it was 403.6 tons, containing 1.3 tons of nitrogen and 0.3 tons of phosphorus. Information about total production and nutrient content in cattle manures by regions of Poland is shown in Figure 25 and Table 40.

Table 40. Production and nutrient content in cattle manures in Poland in 2023.

NUTS_id	Region	Mass (t/a)	Nitrogen (t/a)	Phosphorus (t/a)
PL21	małopolskie	2 051 222.81	6 491.43	1 384.56
PL22	śląskie	1 712 307.74	5 377.33	1 150.91
PL41	wielkopolskie	14 437 045.83	44 775.84	9 553.61
PL42	zachodniopomorskie	976 358.39	3 061.78	649.62
PL43	lubuskie	868 887.21	2 704.24	571.51
PL51	dolnośląskie	1 163 423.65	3 654.50	776.41
PL52	opolskie	1 701 817.68	5 315.31	1 135.01
PL61	kujawsko-pomorskie	6 184 661.77	19 238.53	4 114.11
PL62	warmińsko-mazurskie	6 020 898.51	19 086.28	4 082.47
PL63	pomorskie	2 827 231.34	8 815.77	1 886.01
PL71	łódzkie	5 593 230.51	17 528.27	3 752.16
PL72	świętokrzyskie	1 707 044.32	5 321.93	1 136.10
PL81	lubelskie	4 299 111.65	13 435.58	2 863.76
PL82	podkarpackie	977 103.52	3 102.99	661.91
PL84	podlaskie	14 663 374.95	46 521.15	9 974.44
PL92	mazowieckie	16 243 276.85	51 427.51	11 040.90

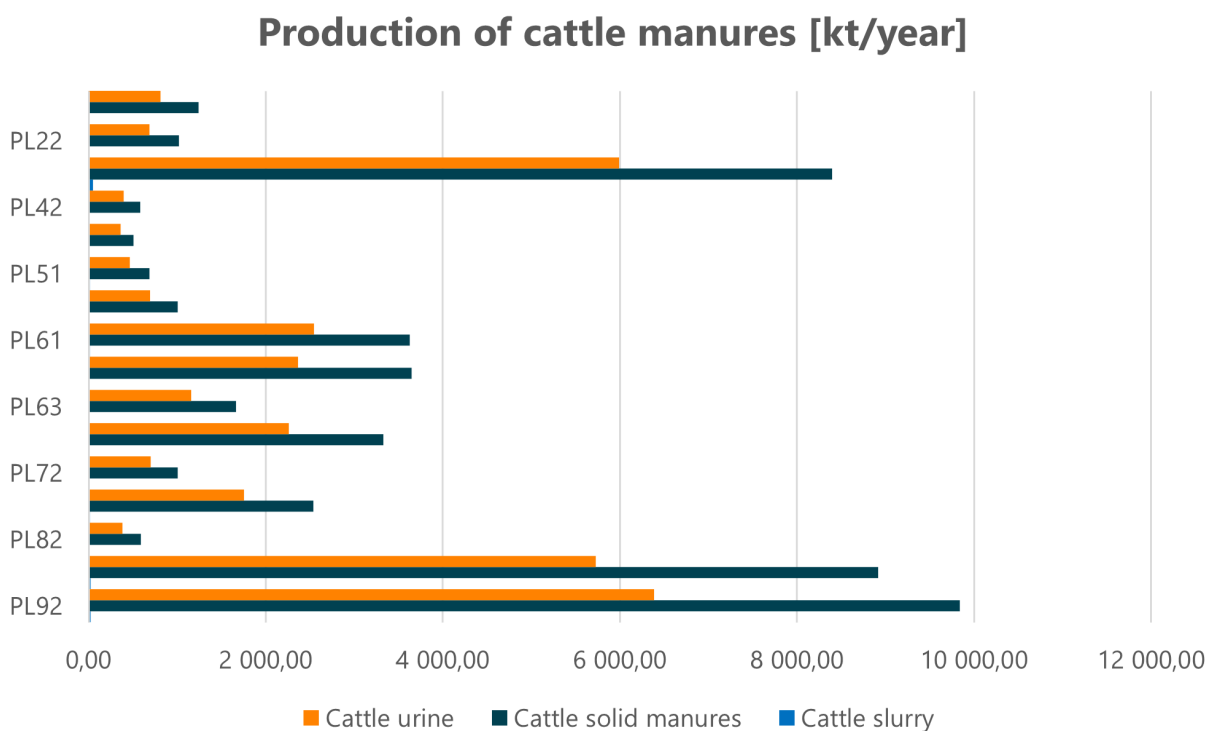


Figure 25. Production of cattle manures in the regions of Poland in 2023.

Pig manure in solid form nationwide amounts to 9 247 324.2 tonnes per year, containing 53 309.7 tonnes of nitrogen and 15 805.3 tonnes of phosphorus. The largest amount of pig manure in this form occurs in the wielkopolskie region (NUTS PL41), where the mass amounts to 2 843 317.0 tonnes, containing 9 027.5 tonnes of nitrogen and 4 865.8 tonnes of phosphorus. The smallest amounts of pig manure are found in the dolnośląskie region (NUTS PL51), where the annual mass amounts to 114 263.9 tonnes, including 362.8 tonnes of nitrogen and 195.5 tonnes of phosphorus. On a national scale, pig manure amounts to 5,591,405.3 tons per year, containing 17 892.5 tons of nitrogen and 1 097.0 tons of phosphorus. The largest amount of manure was found in the wielkopolskie region (NUTS PL41), with an annual mass of 1 719 214.9 tons, containing 5 501.5 tons of nitrogen and 337.3 tons of phosphorus. The smallest amount of manure comes from the dolnośląskie region (NUTS PL51), where it amounts to 69 089.8 tons, containing 221.1 tons of nitrogen and 13.6 tons of phosphorus. Figure 26 and Table 41 show the produced amount and nutrient content in pig manure in different regions of Poland.

Table 41. Production and nutrient content in pig manures in Poland in 2023.

NUTS_id	Region	Mass (t/a)	Nitrogen (t/a)	Phosphorus (t/a)
PL21	małopolskie	356 327.90	1 182.70	403.93
PL22	śląskie	682 230.53	2 393.45	766.84
PL41	wielkopolskie	7 212 547.48	24 466.58	8 149.37
PL42	zachodniopomorskie	1 297 737.85	4 669.78	1 452.77
PL43	lubuskie	525 312.83	1 806.99	592.28
PL51	dolnośląskie	462 884.95	1 632.12	519.88
PL52	opolskie	1 189 364.10	4 087.57	1 341.17
PL61	kujawsko-pomorskie	2 887 348.25	9 749.03	3 264.68
PL62	warmińsko-mazurskie	1 906 021.25	6 654.50	2 144.04
PL63	pomorskie	2 001 178.73	7 121.05	2 244.29
PL71	łódzkie	3 086 295.18	10 827.23	3 469.08
PL72	świętokrzyskie	540 492.38	1 847.55	609.98
PL81	lubelskie	1 304 797.75	4 492.36	1 470.93
PL82	podkarpackie	366 300.45	1 207.51	415.65
PL84	podlaskie	1 043 099.80	3 705.99	1 170.11
PL92	mazowieckie	4 192 721.30	14 718.10	4 712.26

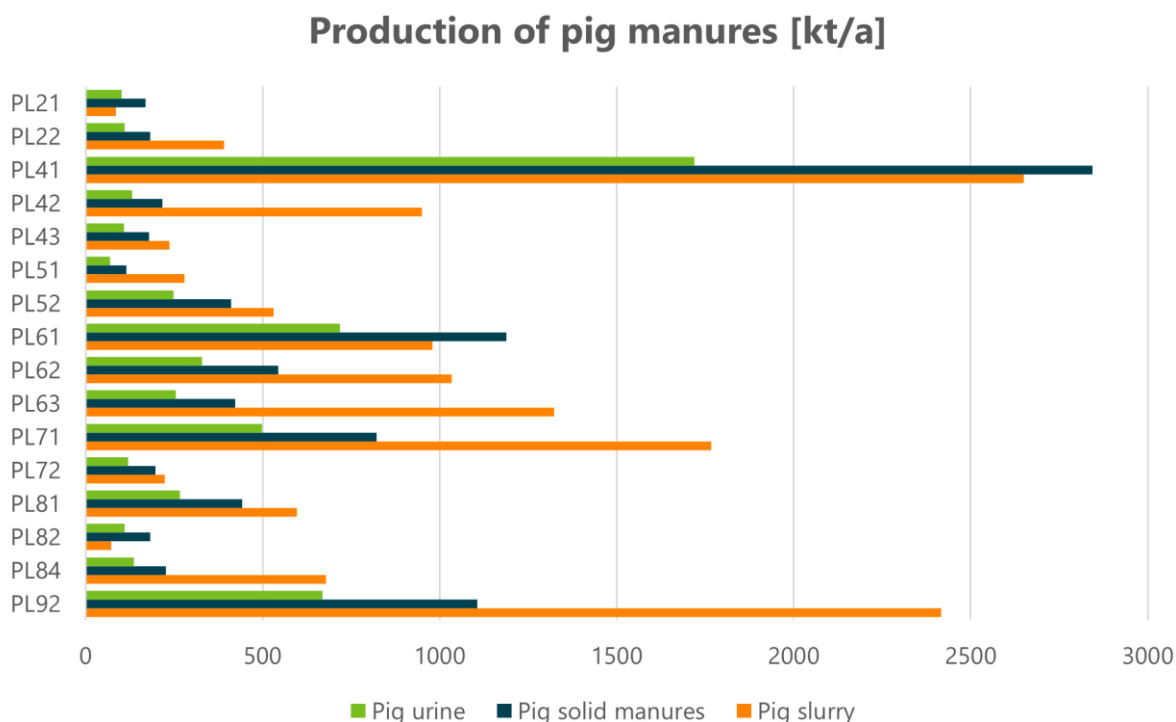


Figure 26. Production of pig manures in the regions of Poland in 2023.

Poultry manure nationwide amounts to 5 724 938.3 tons per year, containing 17 892.5 tons of nitrogen and 8 237.0 tons of phosphorus. The largest amount of poultry manure occurs in the mazowieckie region (NUTS PL92), where the mass was 1 654 939.3 tons, containing 39 081.1 tons of nitrogen and 2 381.1 tons of phosphorus. In turn, the smallest amount of poultry manure comes from the podkarpackie region (NUTS PL82), where the annual mass was 43 506.7 tons, containing 1064.0 tons of nitrogen and 62.6 tons of phosphorus. Total poultry litter (droppings without bedding) in Poland amounts to 568 042.6 tons per year, containing 11

076.8 tons of nitrogen and 817.3 tons of phosphorus. The largest amount is found in the wielkopolskie region (NUTS PL41), where the annual mass is 240116.2 tons, containing 4 682.3 tons of nitrogen and 345.5 tons of phosphorus. The smallest amounts of poultry litter are found in the podlaskie region (NUTS PL84), where the mass is 3 322.9 tons, containing 64.8 tons of nitrogen and 4.8 tons of phosphorus. Total regional production of poultry manures in Poland is included in Figure 27 and Table 42.

Table 42. Production and nutrient content in poultry manures in Poland in 2023.

NUTS_id	Region	Mass (t/a)	Nitrogen (t/a)	Phosphorus (t/a)
PL21	małopolskie	74 516.00	1 711.73	107.21
PL22	śląskie	194 915.72	4 455.72	280.44
PL41	wielkopolskie	1 735 934.53	41 024.23	2 497.66
PL42	zachodniopomorskie	335 950.47	7 852.49	483.37
PL43	lubuskie	241 330.87	7 347.02	347.23
PL51	dolnośląskie	173 345.33	4 026.89	249.41
PL52	opolskie	144 467.56	3 272.03	207.86
PL61	kujawsko-pomorskie	216 567.99	5 175.49	311.60
PL62	warmińsko-mazurskie	278 770.23	8 856.98	401.09
PL63	pomorskie	144 953.07	3 288.33	208.56
PL71	łódzkie	331 409.01	7 605.70	476.83
PL72	świętokrzyskie	112 450.03	2 570.85	161.79
PL81	lubelskie	271 677.93	6 749.73	390.89
PL82	podkarpackie	49 853.07	1 187.79	71.73
PL84	podlaskie	224 227.80	5 307.21	322.62
PL92	mazowieckie	1 762 611.24	41 180.69	2 536.05

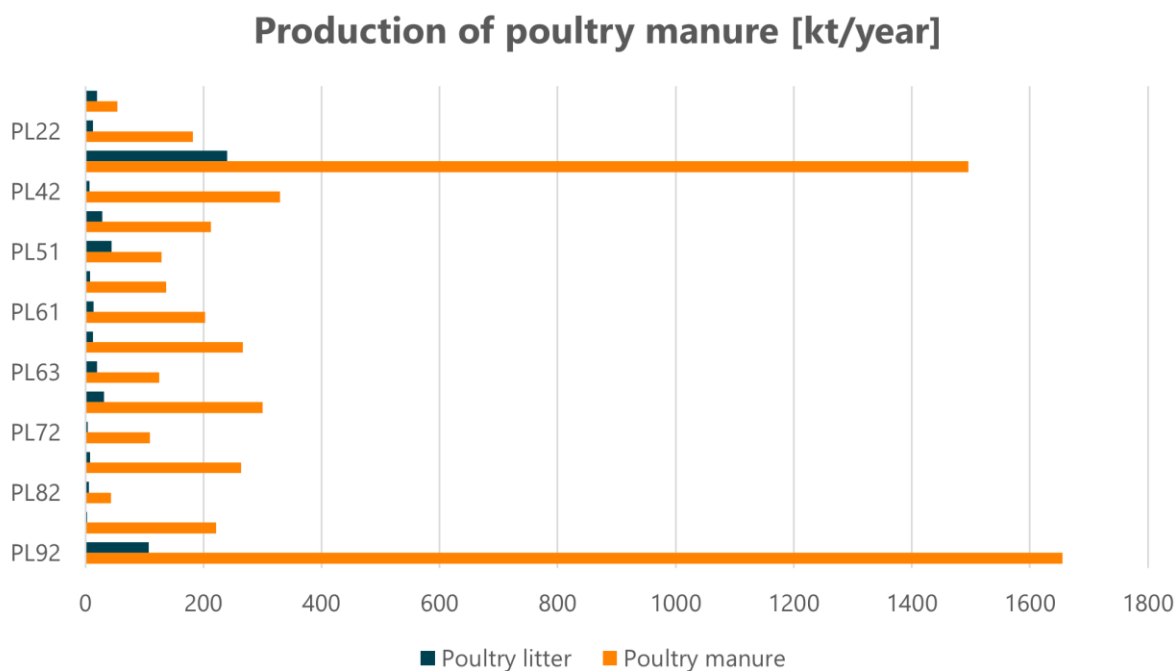


Figure 27. Production of poultry manure in the regions of Poland in 2023.

The largest amount of nitrogen comes from solid cattle manure, providing 153,624.36 tons per year. The largest amount of phosphorus is also found in solid cattle manure, 51,837.58

thousand tons per year. In terms of total mass, cattle generate the largest amount of manure, 81,427 thousand tons per year, making cattle farming the main source of manure. Although pigs and poultry provide less manure, 29,054.66 thousand tons and 6,292.98 thousand tons per year, respectively, poultry is a significant source of nitrogen, providing 151.61 thousand tons per year. The analysis also reveals significant regional differences. Different types of manure have different proportions of nutrients and are dominant in different regions, depending on local husbandry practices. For example, regions with intensive cattle farming will generate more slurry and solid cattle manure, while regions with a higher concentration of pigs will generate more slurry and solid pig manure. A livestock manure production per animal category for each region is shown in Figure 28.

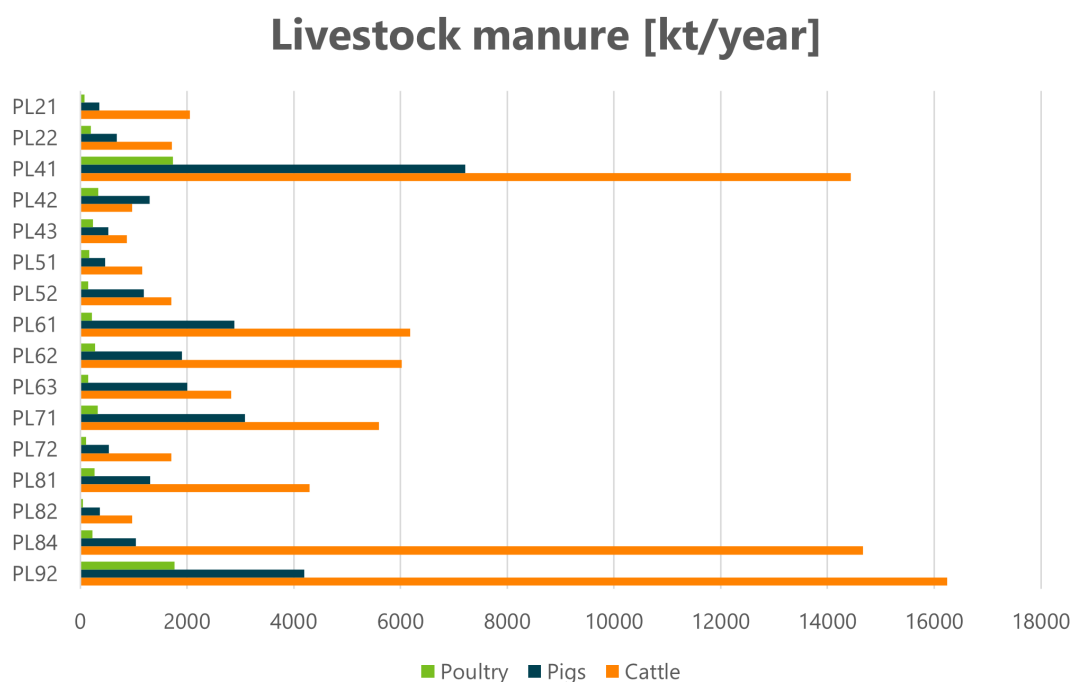


Figure 28. A livestock manure production per animal category for each region in Poland.

Municipal sewage sludge

Municipal sewage sludge in Poland is a small part of recyclable nutrient-rich biomasses. On a national scale, its amount is 580 800.0 tons per year, containing 22 360.8 tons of nitrogen and 15 100.8 tons of phosphorus. For the spatial distribution (Figure 29), the largest amount of municipal sewage sludge is in the mazowieckie region (NUTS PL92), where its annual mass is 91 000.0 tons, containing 3 503.5 tons of nitrogen and 2 366.0 tons of phosphorus. The second region with highest amount is the wielkopolskie region (NUTS PL41) with an annual mass of 69 000.0 tons, 2 656.5 tons of nitrogen and 1 794.0 tons of phosphorus. The smallest amount of municipal sewage sludge is in the opolskie region (NUTS PL52), where the annual mass is 12 600.0 tons, containing 485.1 tons of nitrogen and 327.6 tons of phosphorus, and in the świętokrzyskie region (NUTS PL72), with an annual mass of 13 800.0 tons, 531.3 tons of nitrogen and 358.8 tons of phosphorus. The amount of municipal sewage sludge is explained by population density and advanced urbanization, which directly translates into higher amount.

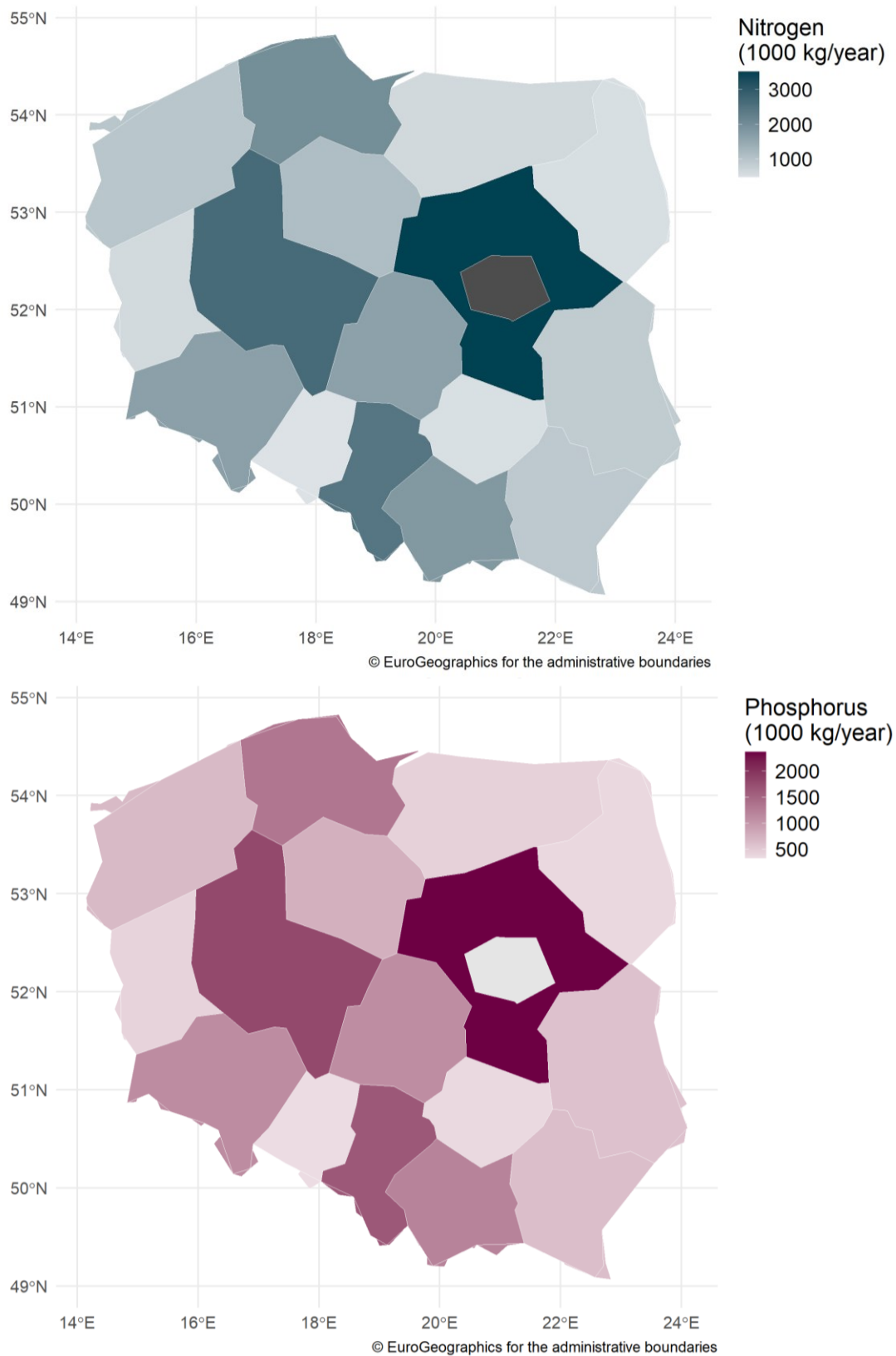


Figure 29. Spatial distribution of nitrogen (above) and phosphorus (below) in sewage sludge in Poland in 2023.

Municipal source-separated biowaste

Municipal biological waste in Poland constitutes a significant part of the recyclable bio-masses. It was estimated that it amounts to 3 596 741.3 tons per year nationwide, containing 26 615.9 tons of nitrogen and 3 452.9 tons of phosphorus. The area with the largest amount of this waste was the śląskie region (NUTS PL22), where the annual mass of waste was 547 846.5 tons, containing 4 054.1 tons of nitrogen and 525.9 tons of phosphorus (Figure 30). The next significant region was the wielkopolskie region (NUTS PL41) with an annual mass of 355 850.9 tons, 2 633.3 tons of nitrogen and 341.6 tons of phosphorus. The smallest amount of municipal biological waste was located in the świętokrzyskie region (NUTS PL72). In this region, this waste amounts to 41 520.9 tons per year, containing 307.3 tons of nitrogen and 39.9 tons of phosphorus. This was the only area in Poland where the amount of waste does not exceed 70 thousand tons per year.

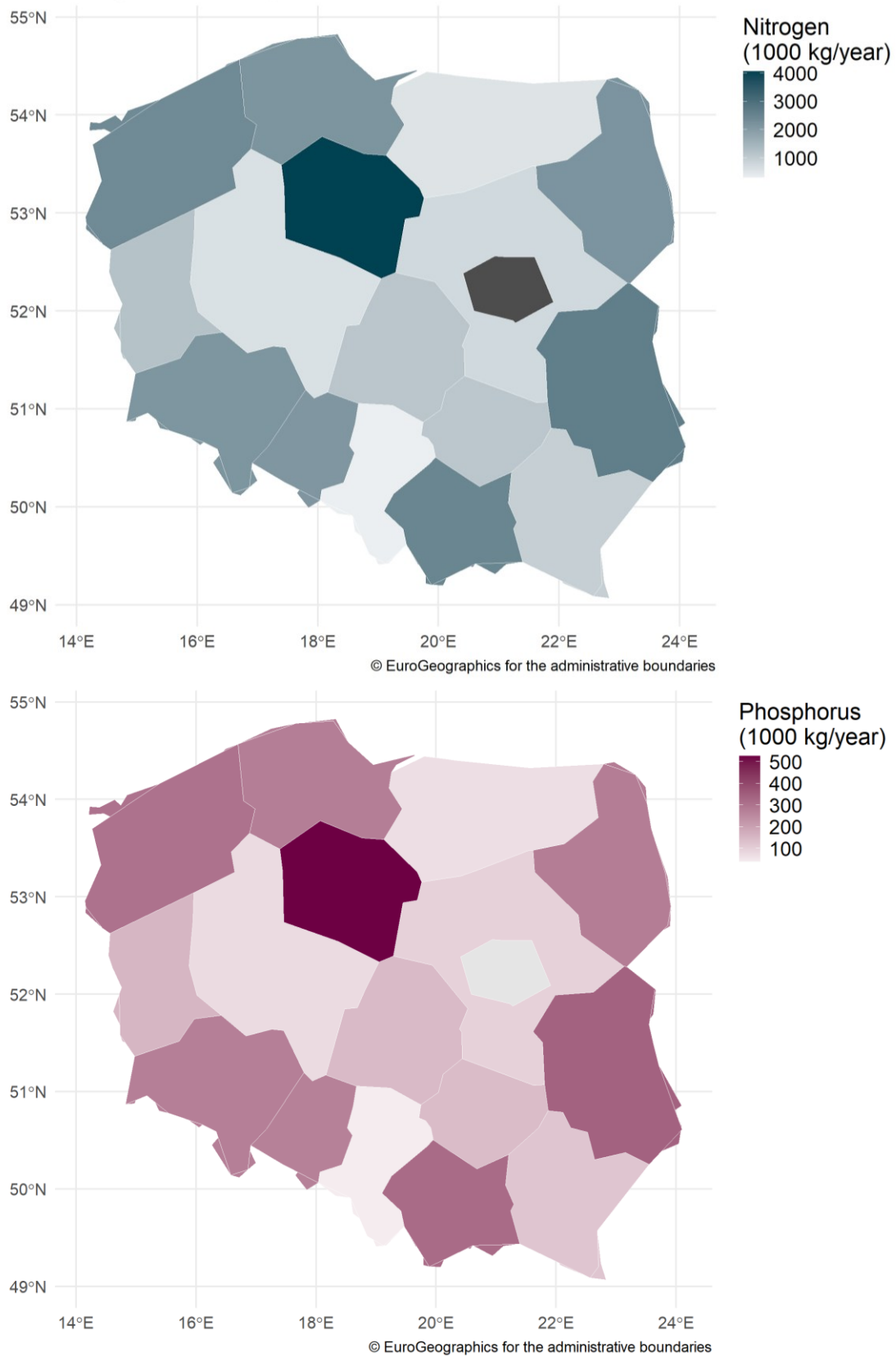


Figure 30. Spatial distribution of nitrogen (above) and phosphorus (below) in municipal bio-waste in Poland in 2023.

Industrial wastes and by-products

In Poland, industrial waste can be divided into animal by-products and food industry by-products. In total, they generate 6 463 619.6 tons of waste per year, containing 80 952.5 tons of nitrogen and 13 964.6 tons of phosphorus. The largest amount of these biomasses comes from the wielkopolskie region (NUTS PL41), where the annual mass of waste was 1 740 613.1 tons, containing 16 883.0 tons of nitrogen and 2 499.4 tons of phosphorus. The smallest amount of waste comes from the świętokrzyskie region (NUTS PL34), with an annual mass of 34 616.5 tons, 407.3 tons of nitrogen and 68.1 tons of phosphorus.

The annual animal by-product production is calculated up to 1 462 175.3 tonnes, containing 40 940.9 tonnes of nitrogen and 8 963.1 tonnes of phosphorus. The largest producer of this waste is the łódzkie region (NUTS PL71) with 354 308.2 tonnes of waste per year, containing 9 920.6 tonnes of nitrogen and 2 171.9 tonnes of phosphorus (Figure 31). The smallest producer is the podkarpackie region (NUTS PL82) with 5 189.5 tonnes of waste, 145.3 tonnes of nitrogen and 31.8 tonnes of phosphorus per year.

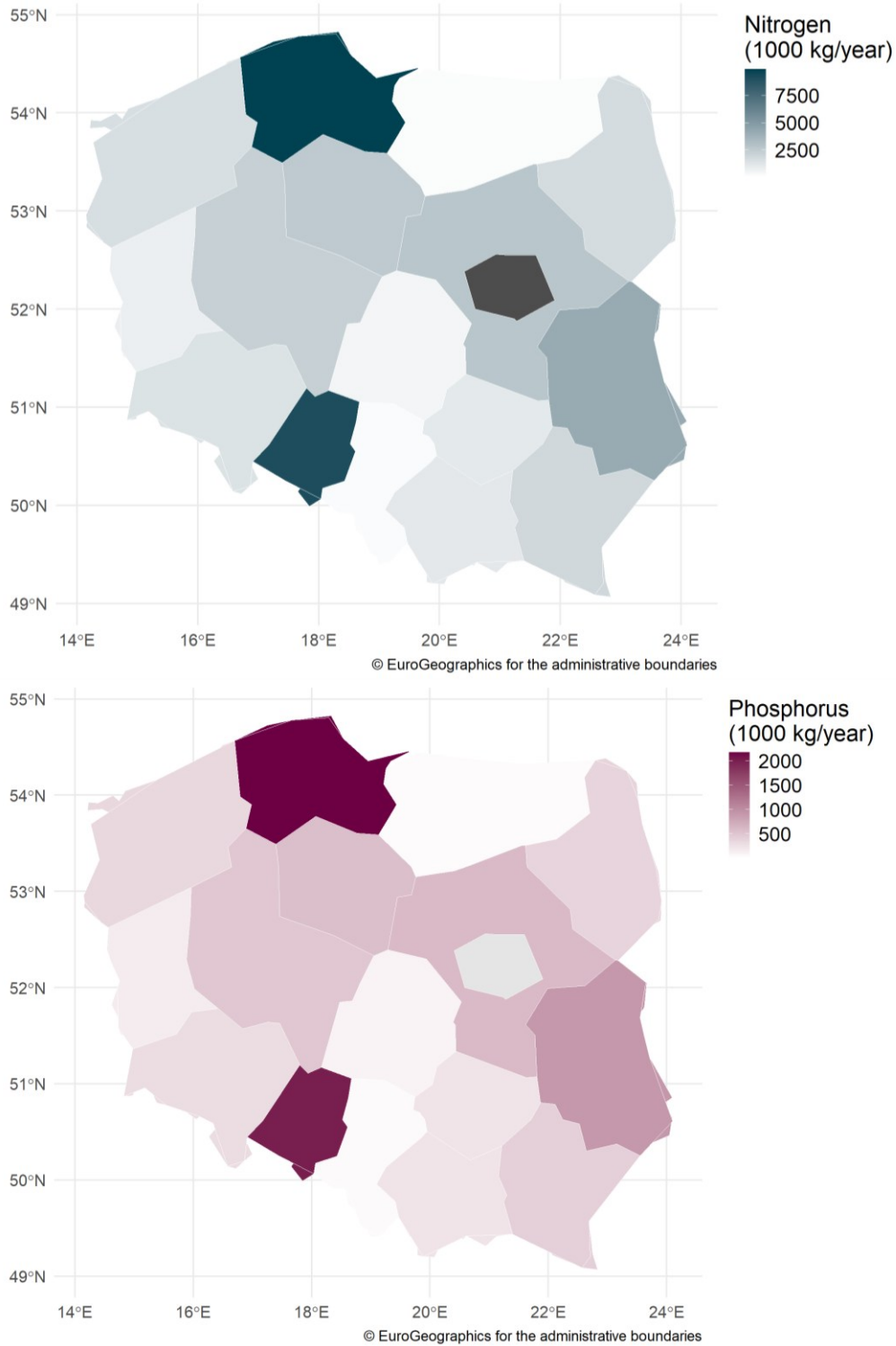


Figure 31. Spatial distribution of nitrogen (above) and phosphorus (below) in animal by-products in Poland in 2023.

Side streams from food industry amounts to 5 001 444.3 tonnes per year, containing 40 011.6 tonnes of nitrogen and 5 001.4 tonnes of phosphorus. The largest amount of this waste comes from the wielkopolskie region (NUTS PL41), where the annual mass was 1 592 708.6 tonnes, containing 12 741.7 tonnes of nitrogen and 1 592.7 tonnes of phosphorus (Figure 32). The smallest amount of waste comes from the lubuskie region (NUTS PL43) with an annual mass of 21 987.3 tonnes, 175.9 tonnes of nitrogen and 22.0 tonnes of phosphorus.

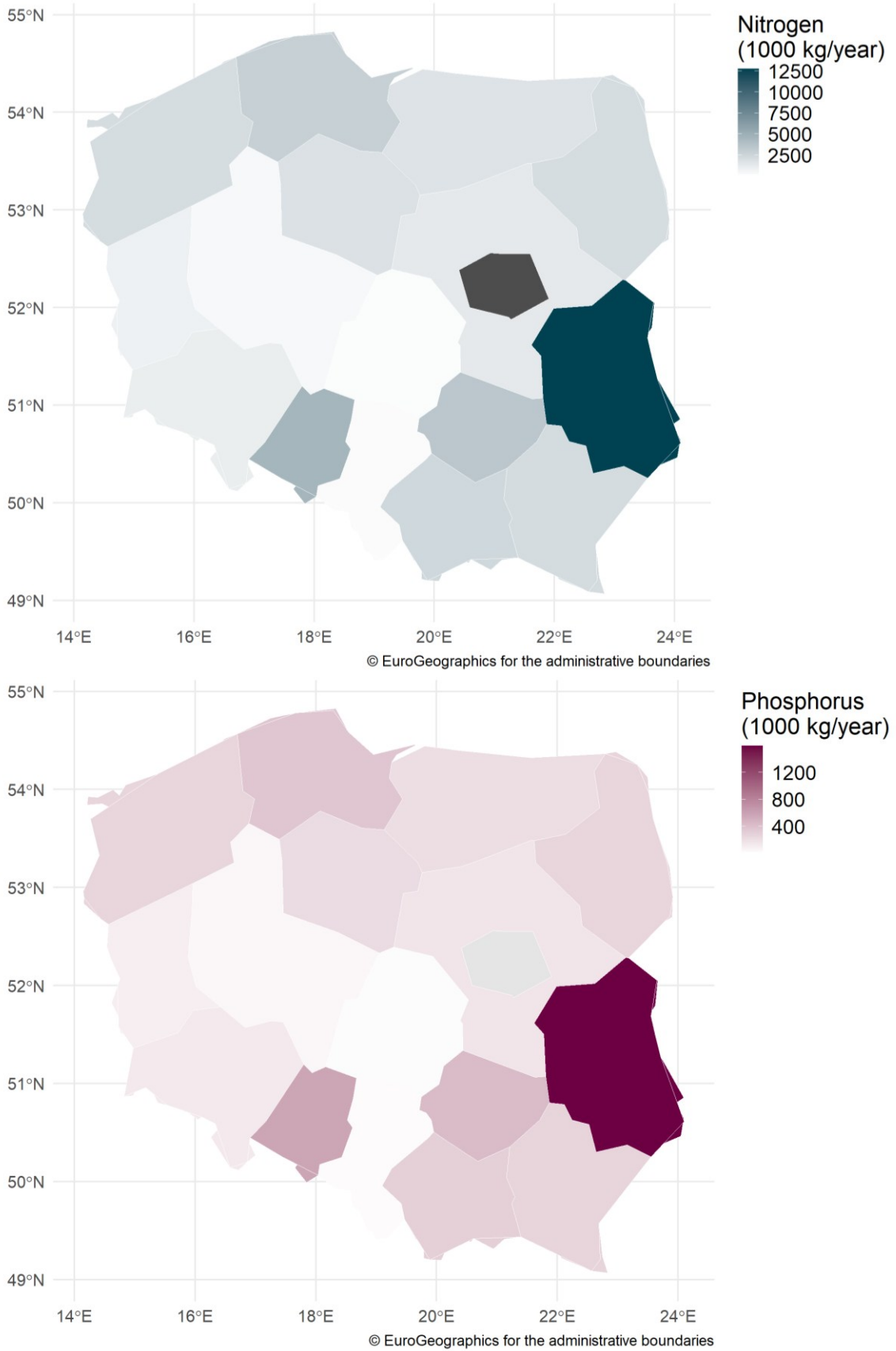


Figure 32. Spatial distribution of nitrogen (above) and phosphorus (below) in food industry side streams in Poland in 2023.

Summary

The spatial distribution of the total nutrient recycling potential in Poland is shown in Figure 33.

Based on the analysis of municipal and industrial waste in Poland, several important conclusions can be drawn (Figures 34 & 35). On a national scale, municipal sewage sludge constitutes a relatively small part of biomass with the potential for recycling nutrients. Their annual amount was 580.8 tons, containing 22.4 tons of nitrogen and 15.1 tons of phosphorus. The largest amount of this waste was generated by the mazowieckie region, which was related to the high population density and high degree of urbanization. In turn, the least sewage sludge was generated in the opolskie and świętokrzyskie regions. Municipal biological waste constitutes a larger share in the total mass of waste, reaching 3 596 741.3 tons per year. They contain 26 615.9 tons of nitrogen and 3 452.9 tons of phosphorus. The largest amount of this waste was generated in the śląskie region, and the smallest in the świętokrzyskie region, which also results from differences in population density and intensity of economic activity in individual regions. Industrial waste, which includes both animal by-products and food industry waste, generates a total of 6 463 619.6 tons per year. They contain significant amounts of nitrogen (80 952.5 tons) and phosphorus (13 964.6 tons). The region generating the most industrial waste was wielkopolskie, while the least of this type of waste comes from the świętokrzyskie region. Animal waste was particularly concentrated in the łódzkie region, while food industry waste dominates in the wielkopolskie region.

In summary, the analysis of waste in Poland shows significant regional variations in the amount and composition of municipal and industrial waste. More populated and industrialized regions generate larger amounts of waste, which emphasizes the need for regionally adapted waste management policies. Furthermore, large amounts of nitrogen and phosphorus in waste indicate significant recycling potential for these components, which can contribute to sustainable resource management and environmental protection in Poland.

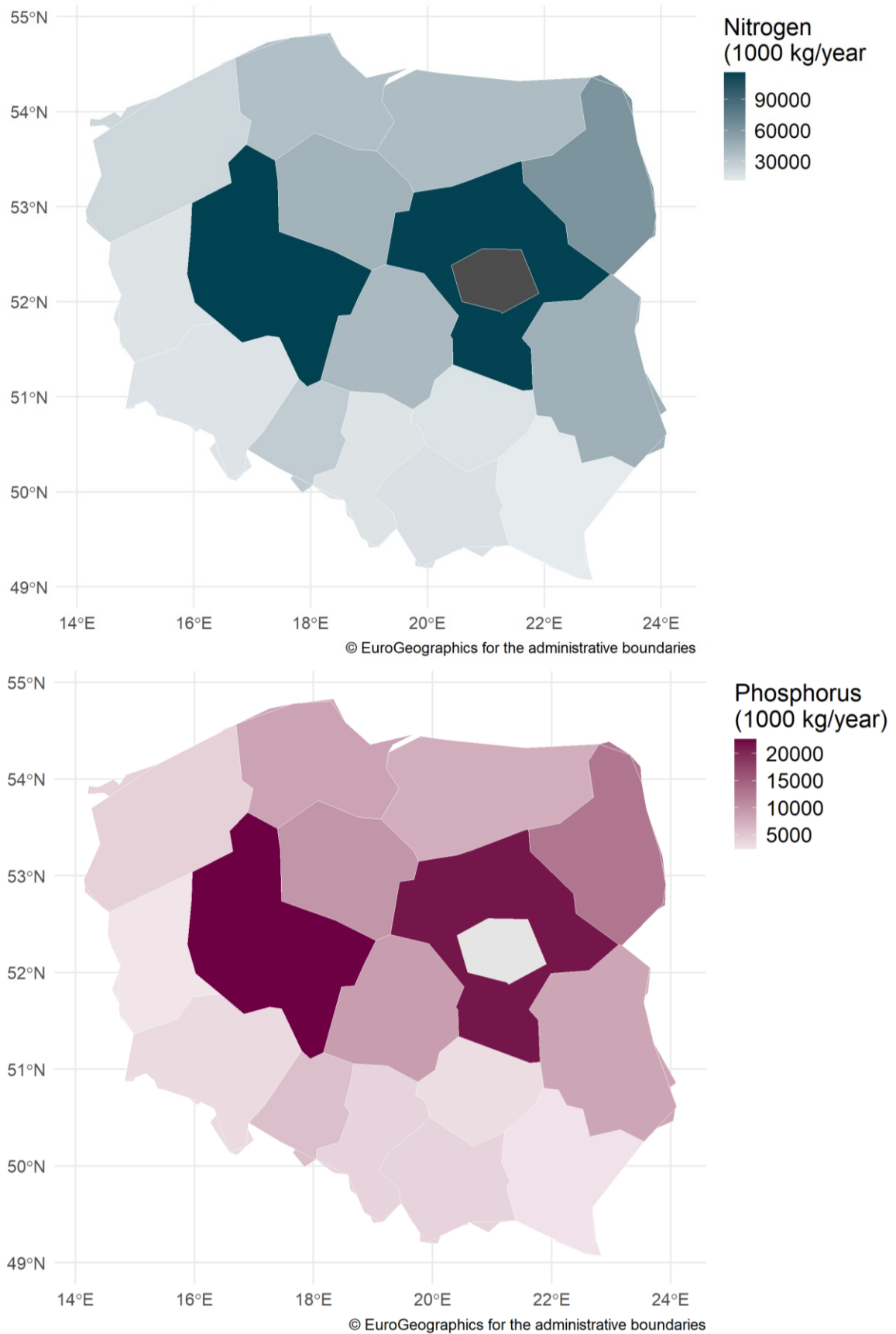


Figure 33. Spatial distribution of nitrogen (above) and phosphorus (below) in recyclable bio-masses in total in Poland (manure, sewage sludge, biowaste, animal by-products and food industry side streams).

Waste mass [kt/year] in 2021

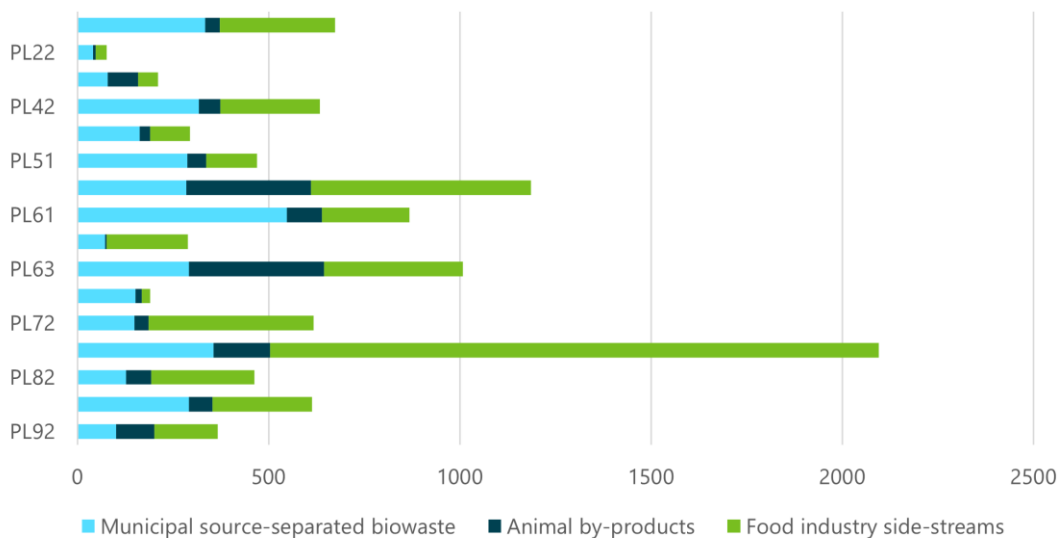


Figure 34. Regional diversity of different types of wastes in Poland.

Municipal sewage sludge [kt/year] in 2022

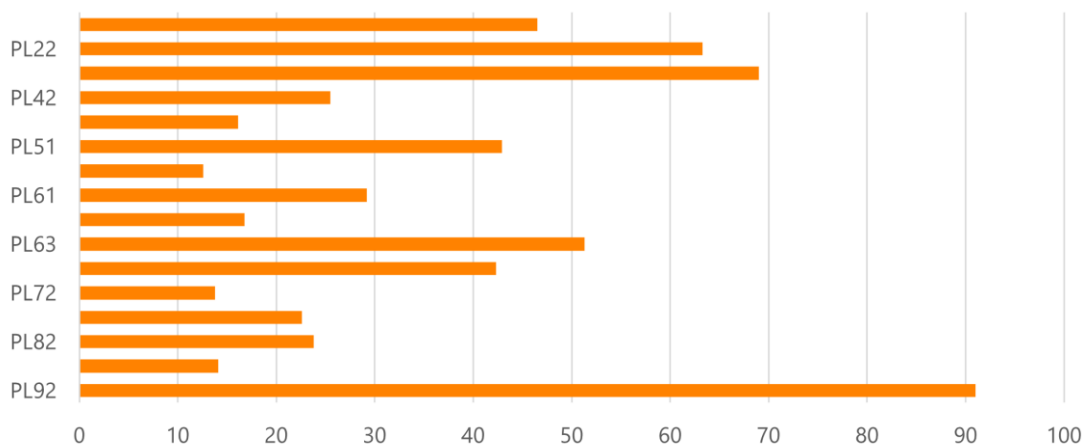


Figure 35. Regional diversity of municipal sewage sludge in Poland.

3.5.3. Comparison of national and EUROSTAT data

Livestock manure

In the analyses, the data on livestock from ARMR was used. This institution specializes in collecting detailed data on Polish agriculture, and its resources are exceptionally precise and up-to-date. ARMR data is also more current than that processed by EU institutions such as Eurostat. This is because ARMR gathers information directly from Polish farmers and entrepreneurs. Eurostat data is less detailed, as its primary focus is on harmonizing statistics across all EU member states rather than conducting in-depth local analyses. Furthermore, due to multi-stage data processing and validation procedures, Eurostat publications may be delayed

compared to those from ARMIR. The differences in results related to livestock rearing also stem from the use of different coefficients. This analysis relied on Polish nutrient coefficients (nitrogen: the Nitrate Program; phosphorus: Fertilizer and Nutrient Balance Advisory System). Eurostat for nitrogen calculation is using The National Centre for Emissions Management (KOBiZE) coefficients, which are based on animal excretion rates.

Municipal biowaste and industrial side streams

For municipal biowaste and industrial waste, information on waste quantities was obtained from the Waste Database (BDO). The database provides detailed information on waste volumes, and the system for collecting this data was specifically designed for Poland. This means it considers national regulation, needs, and the specifics of the waste management system. One of the advantages of using BDO data is the direct access to information on the quantities of specific waste categories in tons. In contrast, Eurostat data on municipal biowaste does not provide separate statistics for its volume. Therefore, to estimate the quantity of this type of waste, a national coefficient for "current biowaste capture" must be used, multiplying it by the population in the respective regions. For industrial animal-derived waste, estimating the quantity requires using Eurostat data on the number of slaughtered domestic animals (cattle, pigs, poultry) processed in slaughterhouses. The total quantity of animal by-products can be calculated by multiplying the number of slaughtered animals by the average amount of slaughter waste per animal and summing up the results to obtain the national total.

Sewage sludge

For municipal sewage sludge, data from National Statistics was utilized. It was determined that National Statistics data serves as a better source for detailed analyses specific to Poland. Eurostat data, while derived from national statistical offices such as National Statistics, undergoes additional processing and harmonization to meet EU standards. National Statistics data, on the other hand, is based on national sources, such as statistical surveys, population censuses, and administrative records, providing more direct and locally relevant insights.

References

- EC 2010. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part III: Project Interim Reports.
- Banks, C.J., Heaven, S., Zhang, Y. & Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (red.) IEA Bioenergy Task 37, 2018:12.
- Nitrate Program 2023, pages 105-110 (in Polish), <https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20230000244/O/D20230244.pdf>
- Phosphorus Program 2023, page 52 (in Polish), https://www.iung.pl/publikacje/2023/program_fosforowy.pdf
- Statistical Yearbook of the Republic of Poland, Chapter II Environmental Protection, 2023. <https://stat.gov.pl/en/topics/statistical-yearbooks/statistical-yearbooks/statistical-yearbook-of-the-republic-of-poland-2023,2,25.html>

Timonen, K., Sinkko, T., Luostarinen, S., Tampio, E. & Joensuu, K., 2019. LCA of Anaerobic Digestion: Emission Allocation for Energy and Digestate. *Journal of Cleaner Production*, 235, 1567-1579. <https://doi.org/10.1016/j.jclepro.2019.06.085>.

3.6. Germany

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3.6.1. Materials and methods

Livestock manure

Data on livestock manure accumulation and the recycling potential of manure nitrogen and phosphorus in Germany is collected according to the animal categories shown in Table -. Spatial data on the same NUTS-level are available for cattle and pigs, but a different dataset is available for poultry. For this report, the most recent numbers on cattle, pigs, and sheep in Germany are obtained from EUROSTAT (*agr_r_animal*) for 2023. Since those numbers were only available on NUTS 1 level, the nutrient recycling potential of manure in Germany is presented for this spatial level for all manure types. The most recent data for the quantity of different categories for poultry and goats on NUTS1-level are available for 2020 on the Genesis-Database (German Data; 41141-0104-LAND).

Since neither the Eurostat database, nor German statistics report the amounts of nitrogen and phosphorus excreted into livestock manure, the nitrogen and phosphorus potentials are calculated by using the number of animals from Eurostat or German statistics and German coefficients (Table) for nutrient excretion into manure by applying the following equations:

$$N\text{-excretion (t/year)} =$$

$$(\text{animal category (heads)} \times N\text{-excretion coefficient of animal category (kg N/head/year)})/1000$$

$$P\text{-excretion (t/year)} =$$

$$(\text{animal category (heads)} \times P\text{-excretion coefficient of animal category (kg P/head/year)})/1000$$

In contrast to Eurostat, the German dataset for poultry contains the sub-category "young hens". For this poultry category, the excretion-coefficient for "other chicken" (N = 0.261 kg /head/year; P= 0.070 kg /head/year) was applied (Table 43).

Table 43. Animal categories, their respective codes and German excretion coefficients for nitrogen and phosphorus (calculated by JKI, basing on DüV 2017).

Code for number of animals (Eurostat)	Animal category	N excretion coefficient (kg N/head/year)	P excretion coefficient (kg P/head/year)
A2010	Bovine animals, less than 1 year old	15.2	2.63
A2020	Bovine animals, 1 to less than 2 years old	38.8	6.29
A2130	Male bovine animals, 2 years old or over	41.3	6.46
A2230	Heifers, 2 years old or over	51.0	6.87
A2300F	Dairy cows	130	19.8
A2300G	Non dairy cows	102	13.10
A3131	Piglets, live weight of under 20 kg	3.7	0.60
A3120	Breeding sows, live weight 50 kg or over	24.8	4.96
A3131	Pigs, from 20 kg to less than 50 kg	9.90	2.20
A3132	Fattening pigs, live weight 50 kg or over	11.1	1.89
A3133	Breeding boars	22.1	4.19
A4100	Live sheep	19.3	1.89
A4200	Live goats	15.2	2.49
A5110O	Laying hens	0.748	0.160
-	Other chicken	0.261	0.070
A5140	Broilers	0.337	0.070
A5210	Ducks	0.576	0.160
A5220	Geese	0.702	0.170
A5230	Turkeys	1.725	0.380

Agricultural plant-based side streams

Cereal Straw

The amount and nutrient content of cereal straw was calculated with the Eurostat-based method of Luostarinen et al. (2021).

Beet leaves

Since no data for the cropping area of sugar beets are available on NUTS2 level for Germany, the nutrient potential of beet leaves was calculated on NUTS1 level. This data for 2024 are obtained from the genesis database (code: 41241-0010). It was further assumed that the average aerial yield (i.e. beet leaves) of sugar beet was 400 dt/ha (Schönberger 2010, Schulze-Lammers & Roller 2010, Schaffner et al. 2011).

The yield of beet leaves was calculated with the following formula:

$$\text{Aerial yield (dt)} = \text{cropping area (ha)} * 400$$

Average N and P contents (kg FM/dt) of beet leaves are from the German StoffBilV (The Ordinance on Nutrient-Flow Balances), being 0.40 kg nitrogen/dt FM and 0.048 kg phosphorus/dt FM).

For the calculation of the N- and P-potential of beet leaves, the following formula was used:

$$\text{N/P-potential (t)} = ((\text{Aerial yield (dt)} * \text{N/P (kg/dt FM)})/1000$$

Haulm

No data for the cropping area of potatoes were available on NUTS 2-level for Germany, accordingly the nutrient potential of haulm was calculated on NUTS 1-level. Data for the cropping area of potatoes in Germany for 2024 were obtained from the genesis database (code: 41241-0010).

For the calculation, it was assumed that the average aerial yield (haulm) of potatoes was 300 dt/ha (Schönberger 2010).

The yield of haulm was calculated with the following formula:

$$\text{Aerial yield (dt)} = \text{cropping area (ha)} * 300$$

Average N-and P-contents (kg FM/dt) of haulm came from the German StoffBiV (The Ordinance on Nutrient-Flow Balances), being 0.20 kg nitrogen/dt FM and 0.02 kg phosphorus/dt FM).

For the calculation of the N- and P-potential of haulm, the following formula was used:

$$\text{N/P-potential (t)} = ((\text{Aerial yield (dt)} * \text{N/P (kg/dt FM)})/1000$$

Municipal biowaste

German municipal biowaste in this report comprises three sub-categories: i) wastes from the compost bin, ii) garden and park wastes, and iii) food wastes from kitchens and canteens (biologically degradable).

To assess the nutrient content of municipal biowastes on a NUTS2 level, a per capita coefficient was calculated for all three sub-categories using the nationwide accumulation (in t/a) in 2022 and the nationwide population for 2022. The amount of accumulated waste for Germany was taken for 2022 from German statistics (Destatis 2024a). For the German population a total number of 83.237.124 was assumed (Eurostat 2024).

The coefficient for the three waste groups was calculated with the following formula (example for compost bin):

$$\text{Coefficient for compost bin (kg/person/a)} = \text{Accumulation of waste in compost bin (Germany total in kg) in 2022/population of Germany in 2022}$$

The resulting coefficients are presented in Table 44.

Table 44. Coefficients for different sub-categories of municipal biowaste in Germany.

Subgroup biowaste	Coefficient (kg/capita)
Organic waste from compost bin	56.0
Garden and park waste (compostable)	62.2
Food wastes from kitchens and canteens (biodegradable)	11.9

To calculate the biowaste accumulation for 2023 on NUTS 2-level, the population for 2023 (Eurostat) of each NUTS 2-region is multiplied with the coefficient for each sub-category as follows:

$$\text{Waste accumulation (t/a)} = (\text{population of 2023 (NUTS 2)} \times \text{coefficient (kg)})/1000$$

For the calculation of the nutrient potential of waste from compost bin and garden and park waste, only numbers for composts are available, hence a mass loss of 50% during the composting process (VHE 2024) is considered for these two sub-categories.

Average nitrogen and phosphorus contents for compost bin and garden and park waste are obtained from Möller and Schultheiss (2014), being N (% FM): 0.94 and P (% FM): 0.20 for compost bin and N (% FM): 0.72 and P (% FM): 0.14 for garden and park waste. DM, N and P contents of food waste from kitchens and canteens are taken from Banks et al. (2018): DM (%): 24.0; N (% DM): 3.1; P (% DM): 0.4.

To assess the nutrient potential of all municipal biowastes on NUTS2 level, the calculated accumulation is multiplied with the respective average N and P values (example organic waste bin compost):

$$N \text{ potential (t/a)} = (\text{organic waste bin accumulation (t/a)/100}) * \text{Nitrogen content (\%)}$$

$$P \text{ potential (t/a)} = (\text{organic waste bin accumulation (t/a) /100}) * \text{Phosphorus content (\%)}$$

Municipal sewage sludge

The nutrient recycling potential of sewage sludge in Germany is calculated for 2023 on NUTS2-level. A per capita coefficient is calculated by using the nationwide accumulation of sewage sludge (t/a) in 2019 (Eurostat, 2024; [env_ww_spd]) and the total population for 2019 (Eurostat, 2024; [[demo_r_d2jan]]) as follows:

$$\text{Coefficient for sewage sludge (kg/person/a)} = \text{Accumulation of sewage sludge (Germany total in kg [DM]) in 2019/population of Germany in 2019}$$

The per capita coefficient for sewage sludge accumulation in Germany is 21.08 kg/capita/a.

The accumulation of sewage sludge in each NUTS 2-region in Germany is calculated for 2023 by using to following formula:

$$\text{Sewage sludge accumulation (t/a)} = ((\text{population of 2023 [NUTS 2]} \times (\text{coefficient (kg/head/a)}))/1000)$$

The numbers for the population for 2023 on NUTS 2 levels are obtained from Eurostat [demo_r_d2jan], as well.

The values for average nitrogen and phosphorus contents of European sewage sludges are taken from the EC (2010): N (% DM): 3.85; P (% DM): 2.6.

For the calculation of the nutrient recycling potential of each German NUTS 2 region, the following calculation was applied:

$$N \text{ potential (t/a)} = (\text{Sewage sludge amount (t DM)/100}) * N \text{ content (\% DM)}$$

$$P \text{ content (t/a)} = \text{Sewage sludge amount (t DM)/100}) * P \text{ content (\% DM)}$$

Industrial side streams

Animal by-products

To assess the nutrient recycling potential of animal by-products as slaughtering waste, the numbers for slaughtered domestic animals for 2023 are taken for pigs, cattle, goat and sheep (Destatis 2024b) and for slaughtered poultry from BMEL. Only data for Germany (total) were accessible.

The amount of slaughtering waste per head of pig, cattle, and poultry is taken from Finnish Environment Institute (2000) and per head of goats and sheep from Mozhiarasi and Natharajan (2022).

The calculation of the amount of slaughtering waste accumulating in Germany per year was conducted using the equation:

$$\text{Slaughtering waste (t/a)} = (\text{animals slaughtered (heads)} * \text{slaughtering waste average (kg)}) / 1000$$

Average N and P content of slaughtering waste for pig, cattle, poultry, goats, and sheep were taken from the FAO (2018). The nutrient content in all slaughtering waste was calculated with the equation:

$$\text{N-potential (t/a)} = (\text{slaughtering waste (t)} / 100) * \text{N-content (\%)}$$

$$\text{P-potential (t/a)} = (\text{slaughtering waste (t)} / 100) * \text{P-content (\%)}$$

Brewer's spent grain (BSG)

Brewer's spent grain (BSG) is a waste from the brewing industry. In Germany, 77 977 880 hl of beer was produced from malt in 2023. This includes alcoholic and non-alcoholic beer, and beer containing $\leq 0.5\%$ by volume of alcohol (Eurostat: ds-056120). The accumulation of BSG per year is calculated assuming the accumulation of 20 kg BSG per hl of beer produced (Gupta et al., 2010).

Average nitrogen and phosphorus contents of ensilaged BSG are taken from the German StoffBiIV (The Ordinance on Nutrient-Flow Balances), being 25%DM, 40 kg nitrogen/t DM and 6.0 kg phosphorus/t DM.

The amount of beer brewed in Germany is only available for Germany (total); the nutrient potential of BSG was calculated on NUTS 0-level by using the following formulas:

$$\text{Accumulation of BSG (t [DM])} = ((\text{Beer produced in Germany (hl/a)} * 20) / 1000) * 0.25$$

$$\text{N in BSG (t/a)} = (\text{BSG amount (t/a)} * \text{N-content of BSG [kg/t]}) / 1000$$

$$\text{P in BSG (t/a)} = (\text{BSG amount (t/a)} * \text{P-content of BSG [kg/t]}) / 1000$$

Whey

Whey is a liquid by-product from cheese or curd production. It contains approx. 90% of milk FM and 50% of milk DM. Whey also contains relatively high amounts nutrient (Möller & Schultheiss 2014). To estimate whey production in Germany, data for the total accumulation of whey is taken from the database "annual productions of dairy products" (D5000 Whey EUROSTAT NewCronos (apro_mk_pobta and apro_mk_farm)) and the ratio between sweet and

sour whey is assumed as being 80:20 (Benecke 2011). The average DM (%), nitrogen and phosphorus contents of sweet and sour whey (StoffBiIV 2017) are 6.0%DM, 21.6 kgN/tDM and 6.8 kgP/tDM for sweet whey and 6.4%DM, 15.8 kgN/tDM and 12.1 kgP/tDM for sour whey.

The N and P contents in all whey produced is calculated as follows:

$$\text{Accumulation of sweet whey (t/DM)} = (\text{total accumulation of whey (t)} * 0.8) * 0.06$$

$$\text{Accumulation of sour whey (t/DM)} = (\text{total accumulation of whey (t)} * 0.2) * 0.064$$

$$\text{N-potential (t/a)} = (\text{Accumulation DM} * \text{N-content (kg/t DM)})/1000$$

$$\text{P-potential (t/a)} = (\text{Accumulation DM} * \text{P-content (kg/t DM)})/1000$$

Grape pomace

Grape pomace is a by-product from wine production from grapes. It contains skin, pulp, seeds and stem of the fruit. The amount of grapes produced in Germany in 2023 is from Eurostat database (tag00121). The share of grape pomace from grape yield for wine is obtained from Oliveira & Duarte (2016), the average DM, N and P contents of grape pomace from Ferrer et al. (2001). Grape pomace is 13.0% of grape yield and contains 26.4%DM, 1.73%N and 0.28%P.

The amount of grape pomace produced in Germany per year is then calculated on NUTS1-level with the following equation:

$$\text{Grape pomace amount (t/a)} = (\text{Grape yield for wine (t/a)/100}) * \text{Share of grape pomace (\%)}$$

The N and P in grape pomace is calculated as follows:

$$\text{N in grape pomace (t/a)} = (\text{Grape pomace amount (t/a)/100}) * \text{Nitrogen content of grape pomace (\% FM)}$$

$$\text{Grape pomace (t DM)} = (\text{Grape pomace (t FM)/100}) * 26.4$$

$$\text{P in grape pomace (t/a)} = (\text{Grape pomace amount (t/a)/100}) * \text{Phosphorus content of grape pomace (\% DM)}$$

3.6.2. Nutrient recycling potential in Germany

Germany hosts a significant potential for nutrient recycling (Table 45).

Table 45. The amount and nutrient content of different recyclable biomasses in Germany.

	Mass (t/a)	Ntot (t/a)	Ptot (t/a)
Livestock manure	-	1 061 860	172 665
Agricultural side streams	-	88 234	10 607
Municipal biowaste	10 977 974	48 564	9 363
Sewage sludge	1 778 096*	68 457	46 231
Animal by-products	2 305 185	61 409	13 773
Industrial side streams	18 164 755	38 621	10 370
Total		1 367 145	263 009

*(tDM/a)

Livestock manure

The calculation of nutrients in manure is based on the different animal categories and their corresponding excretion coefficients. Thus, a distinction between slurry, urine and solid manure is not possible. Accordingly, only the amount of nutrients in the manure of the different animal categories (cattle, pig, poultry, sheep and goats) is presented here (Table 46). The spatial distribution of the manure nutrients is further depicted as maps (Figure 36).

Table 46. N and P-potential of different manure from different animal categories for Germany for 2020 (goat and poultry) resp. 2023 (cattle, pig, sheep) on NUTS 1-level.

Nuts code and region	Manure N (t/year)	Manure P (t/year)	Cattle manure N (t/year)	Cattle manure P (t/year)	Pig manure N (t/year)	Pig manure P (t/year)	Sheep and goat manure N (t/year)	Sheep and goat manure P (t/year)	Poultry manure N (t/year)	Poultry manure P (t/year)
DE1 Baden-Württemberg	82 877	13 082	61 580	9 356	11 773	2 171	4 595	484	4 929	1 072
DE2 Bayern	230 344	36 255	192 868	29 553	23 625	4 337	5 697	597	8 154	1 768
DE3 Berlin	58	8.1	57	7.9	-	-	0.9	0.1	0.1	0.02
DE4 Brandenburg	40 777	6 434	30 469	4 507	4 756	886	1 500	153	4 051	888
DE5 Bremen	581	88	581	88	-	-	0.4	0.1	0.028	0.008
DE6 Hamburg	354	52	349	51	-	-	1.0	0.2	3.6	0.8
DE7 Hessen	34 358	5 270	26 545	3 984	3 648	669	2 459	251	1 706	367
DE8 Mecklenburg-Vorpommern	43 999	7 075	32 115	4 815	5 535	1 046	1 333	134	5 016	1 081
DE9 Niedersachsen	264 757	45 192	149 147	22 904	68 044	12 471	3 463	349	44 104	9 468
DEA Nordrhein-Westfalen	145 589	24 406	78 009	11 938	55 874	10 273	3 110	318	8 596	1 878
DEB Rheinland-Pfalz	23 856	3 591	20 734	3 104	909	168	1 384	142	830	177
DEC Saarland	2 964	446	2 696	403	19	3.5	126	13	123	26
DED Sachsen	40 930	6 529	31 599	4 776	4 367	832	1 391	144	3 574	778
DEE Sachsen-Anhalt	37 972	6 534	19 493	2 941	8 706	1 626	1 269	131	8 504	1 836
DEF Schleswig-Holstein	80 859	12 544	65 015	9 902	9 961	1 833	3 888	385	1 994	424
DEG Thüringen	28 530	4 499	18 744	2 800	5 449	1 007	2 237	233	2 100	459
DE Germany (total)	1 061 860	172 665	730 001	111 131	202 888	37 363	32 457	3 334	96 514	20 837

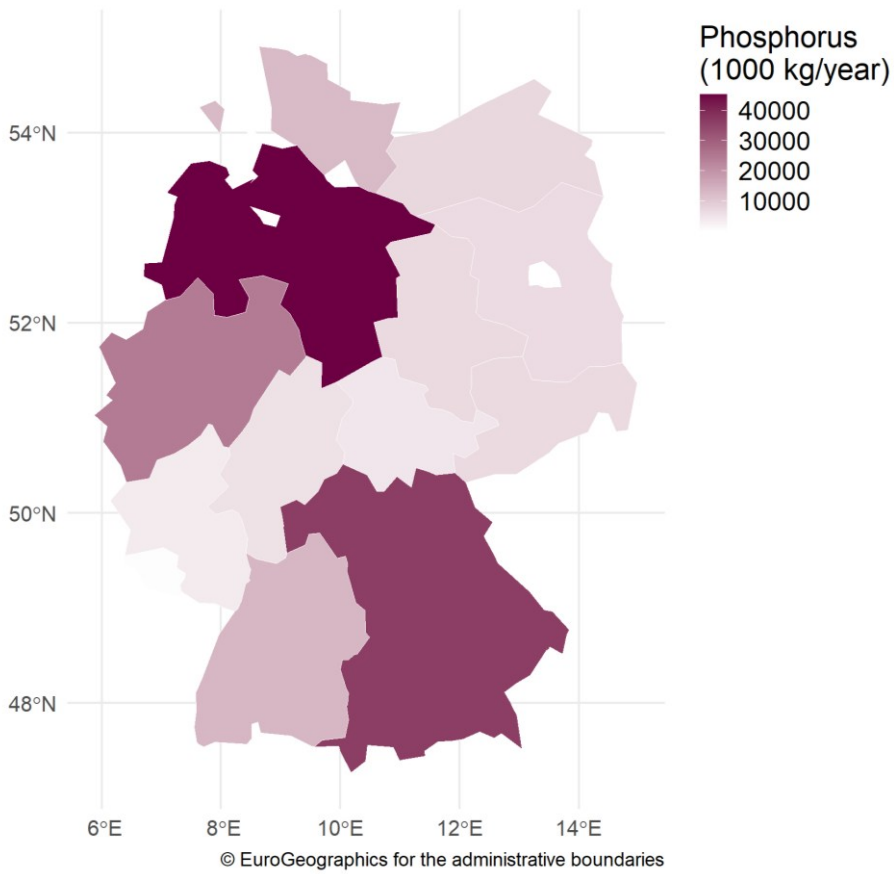
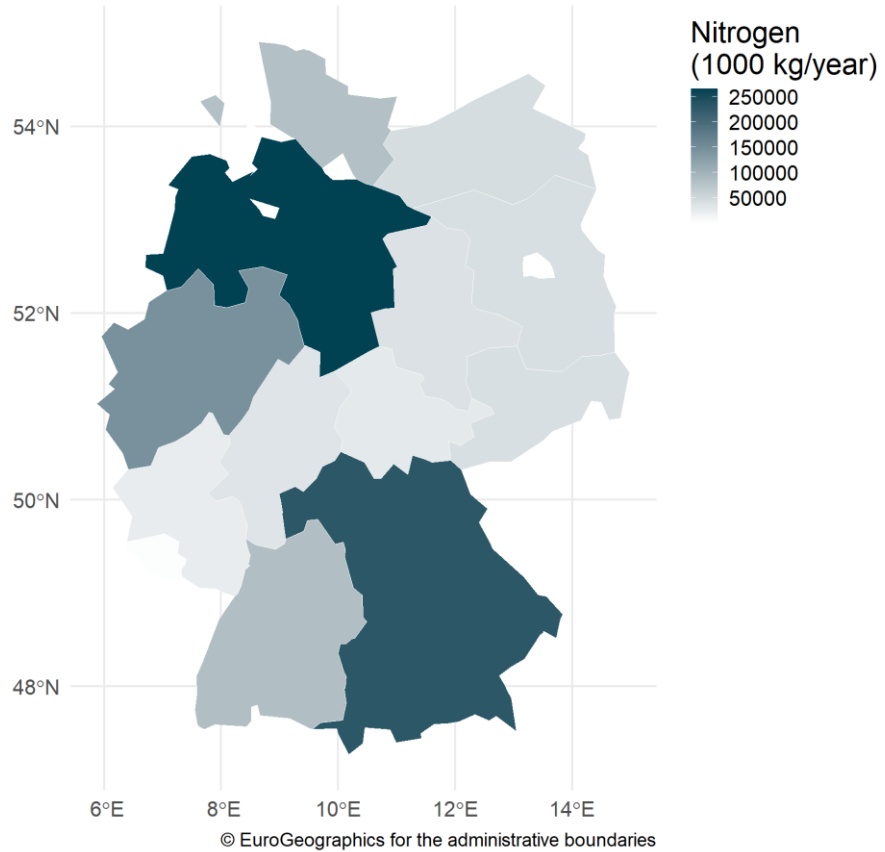


Figure 36. Spatial distribution of nitrogen (above) and phosphorus (below) in livestock manure in Germany.

Agricultural plant-based side streams

The German agriculture produces significant amount of plant-based side streams as cereal straw, sugar beet leaves and haulm. Their quantities and nutrient contents are presented in Tables 47-49.

Table 47. Production and nutrient content in cereal straw in Germany.

Nuts Code and region	Amount (t/a)	Nitrogen (t/a)	Phosphorus (t/a)
DE1 Baden-Württemberg	2 594	11.16	2.231
DE2 Bayern	5 984	25.73	5.146
DE4 Brandenburg	2 507	10.78	2.156
DE7 Hessen	1 807	7.77	1.554
DE8 Mecklenburg-Vorpommern	3 852	16.56	3.313
DE9 Niedersachsen	5 445	23.41	4.683
DEA Nordrhein-Westfalen	3 342	14.37	2.874
DEB Rheinland-Pfalz	1 261	5 420	1.085
DEC Saarland	105	0.45	0.091
DED Sachsen	2 300	9.89	1.978
DEE Sachsen-Anhalt	3 625	15.59	3.118
DEF Schleswig-Holstein	2 414	10.38	2.076
DEG Thüringen	2 345	10.08	2.017
DE Germany (total)	37 582	161.6	32.321

Table 48. Production and nutrient content in sugar beet leaves in Germany.

NUTS Code and region	Crop area (ha)	Aerial yield (dt)	Nitrogen (t/a)	Phosphorus (t/a)
DE1 Baden-Württemberg	18 900	7 560 000	3 024	378
DE2 Bayern	68 000	27 200 000	10 880	1 360
DE3 Berlin	-	-	-	-
DE4 Brandenburg	6 100	2 440 000	976	122
DE5 Bremen	-	-	-	-
DE6 Hamburg	-	-	-	-
DE7 Hessen	18 300	7 320 000	2 928	366
DE8 Mecklenburg-Vorpommern	33 700	13 480 000	5 392	674
DE9 Niedersachsen	122 700	49 080 000	19 632	2 454
DEA Nordrhein-Westfalen	61 200	24 480 000	9 792	1 224
DEB Rheinland-Pfalz	17 800	7 120 000	2 848	356
DEC Saarland	-	-	-	-
DED Sachsen	16 900	6 760 000	2 704	338
DEE Sachsen-Anhalt	54 400	21 760 000	8 704	1 088
DEF Schleswig-Holstein	10 000	4 000 000	1 600	200
DEG Thüringen	14 000	5 600 000	2 240	280
DE Germany (total)	442 000	176 800 000	70 720	8 840

Table 49. Production and nutrient content in haulm in Germany.

NUTS Code and region	Crop area (ha)	Aerial yield (dt)	Nitrogen (t/a)	Phosphorus (t/a)
DE1 Baden-Württemberg	5 300	1 590 000	318	32
DE2 Bayern	35 800	10 740 000	2 148	215
DE3 Berlin	-	-	-	-
DE4 Brandenburg	10 700	3 210 000	642	64
DE5 Bremen	-	-	-	-
DE6 Hamburg	-	-	-	-
DE7 Hessen	3 900	1 170 000	234	23
DE8 Mecklenburg-Vorpommern	13 700	4 110 000	822	82
DE9 Niedersachsen	139 800	41 940 000	8 388	839
DEA Nordrhein-Westfalen	45 900	13 770 000	2 754	275
DEB Rheinland-Pfalz	6 700	2 010 000	402	40
DEC Saarland	100	30 000	6 0	0.6
DED Sachsen	5 400	1 620 000	324	32
DEE Sachsen-Anhalt	13 600	4 080 000	816	82
DEF Schleswig-Holstein	7 100	2 130 000	426	43
DEG Thüringen	1 200	360 000	72	7.2
DE Germany (total)	289 200	86 760 000	17 352	1 735

Municipal biowaste

Municipal biowaste can be divided into three sub-categories and their amount and nutrient content calculated separately. The sub-categories are waste bin compost, garden and park waste, and food waste from kitchens and canteens. Altogether nearly 11 million tons of such biowaste is produced containing 48 564 tons of nitrogen and 9 363 tons of phosphorus (Table 50).

The spatial distribution of the municipal biowaste follows the population density of the different German regions with the highest production in the regions of Stuttgart, Oberbayern, Berlin, Darmstadt, Düsseldorf, Köln and Arnberg (Figure 37).

Table 50. Production and nutrient content in municipal biowaste in total and in three sub-categories in Germany in 2023.

NUTS code and region	Municipal biowaste produced (t FM/a)*	Organic waste bin compost N (t/a)	Organic waste bin compost P (t/a)	Garden and park waste compost N (t/a)	Garden and park waste compost P (t/a)	Food waste N (t/a)	Food waste P (t/a)	Total nitrogen (t/a)	Total phosphorus (t/a)
DE11 Stuttgart	547 325	1 107	236	942	183	371	48	2 421	467
DE12 Karlsruhe	370 674	750	160	638	124	252	32	1 640	316
DE13 Freiburg	302 261	612	130	520	101	205	26	1 337	258
DE14 Tübingen	247 687	501	107	426	83	168	22	1 096	211
DE21 Oberbayern	624 875	1 264	269	1 076	209	424	55	2 764	533
DE22 Niederbayern	165 785	335	71	285	56	113	15	733	141
DE23 Oberpfalz	147 539	299	64	254	49	100	13	653	126
DE24 Oberfranken	139 736	283	60	241	47	95	12	618	119
DE25 Mittelfranken	234 995	475	101	405	79	159	21	1 040	200
DE26 Unterfranken	173 648	351	75	299	58	118	15	768	148
DE27 Schwaben	253 238	512	109	436	85	172	22	1 120	216
DE3 Berlin	488 687	989	210	841	164	332	43	2 162	417
DE4 Brandenburg	334 853	677	144	577	112	227	29	1 481	286
DE5 Bremen	89 124	180	38	153	30	60	8	394	76
DE6 Hamburg	246 230	498	106	424	82	167	22	1 089	210
DE71 Darmstadt	532 003	1 076	229	916	178	361	47	2 353	454
DE72 Gießen	138 899	281	60	239	47	94	12	614	118
DE73 Kassel	160 833	325	69	277	54	109	14	711	137
DE8 Mecklenburg-Vorpommern	211 908	429	91	365	71	144	19	937	181
DE91 Braunschweig	209 629	424	90	361	70	142	18	927	179
DE92 Hannover	283 700	574	122	489	95	193	25	1 255	242
DE93 Lüneburg	228 666	463	98	394	77	155	20	1 012	195
DE94 Weser-Ems	337 329	683	145	581	113	229	30	1 492	288
DEA1 Düsseldorf	684 657	1 385	295	1 179	229	465	60	3 029	584
DEA2 Köln	589 195	1 192	254	1 015	197	400	52	2 606	503
DEA3 Münster	346 714	701	149	597	116	235	30	1 534	296
DEA4 Detmold	271 373	549	117	467	91	184	24	1 200	231

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NUTS code and region	Municipal biowaste produced (t FM/a)*	Organic waste bin compost N (t/a)	Organic waste bin compost P (t/a)	Garden and park waste compost N (t/a)	Garden and park waste compost P (t/a)	Food waste N (t/a)	Food waste P (t/a)	Total nitrogen (t/a)	Total phosphorus (t/a)
DEA5 Arnsberg	468 581	948	202	807	157	318	41	2 073	400
DEB1 Koblenz	198 130	401	85	341	66	134	17	876	169
DEB2 Trier	71 127	144	31	122	24	48	6	315	61
DEB3 Rheinhessen-Pfalz	271 991	550	117	468	91	185	24	1 203	232
DEC Saarland	129 180	261	56	222	43	88	11	571	110
DED2 Dresden	207 987	421	90	358	70	141	18	920	177
DED4 Chemnitz	183 692	372	79	316	62	125	16	813	157
DED5 Leipzig	140 069	283	60	241	47	95	12	620	119
DEE Sachsen-Anhalt	284 557	576	122	490	95	193	25	1 259	243
DEF Schleswig-Holstein	384 322	778	165	662	129	261	34	1 700	328
DEG Thüringen	276 775	560	119	477	93	188	24	1 224	236
DE Germany (total)	10 977 974	22 211	4 726	18 903	3 676	7 450	961	48 564	9 363

* Municipal biowaste = waste bin compost + garden and park waste + food waste from kitchens and canteens

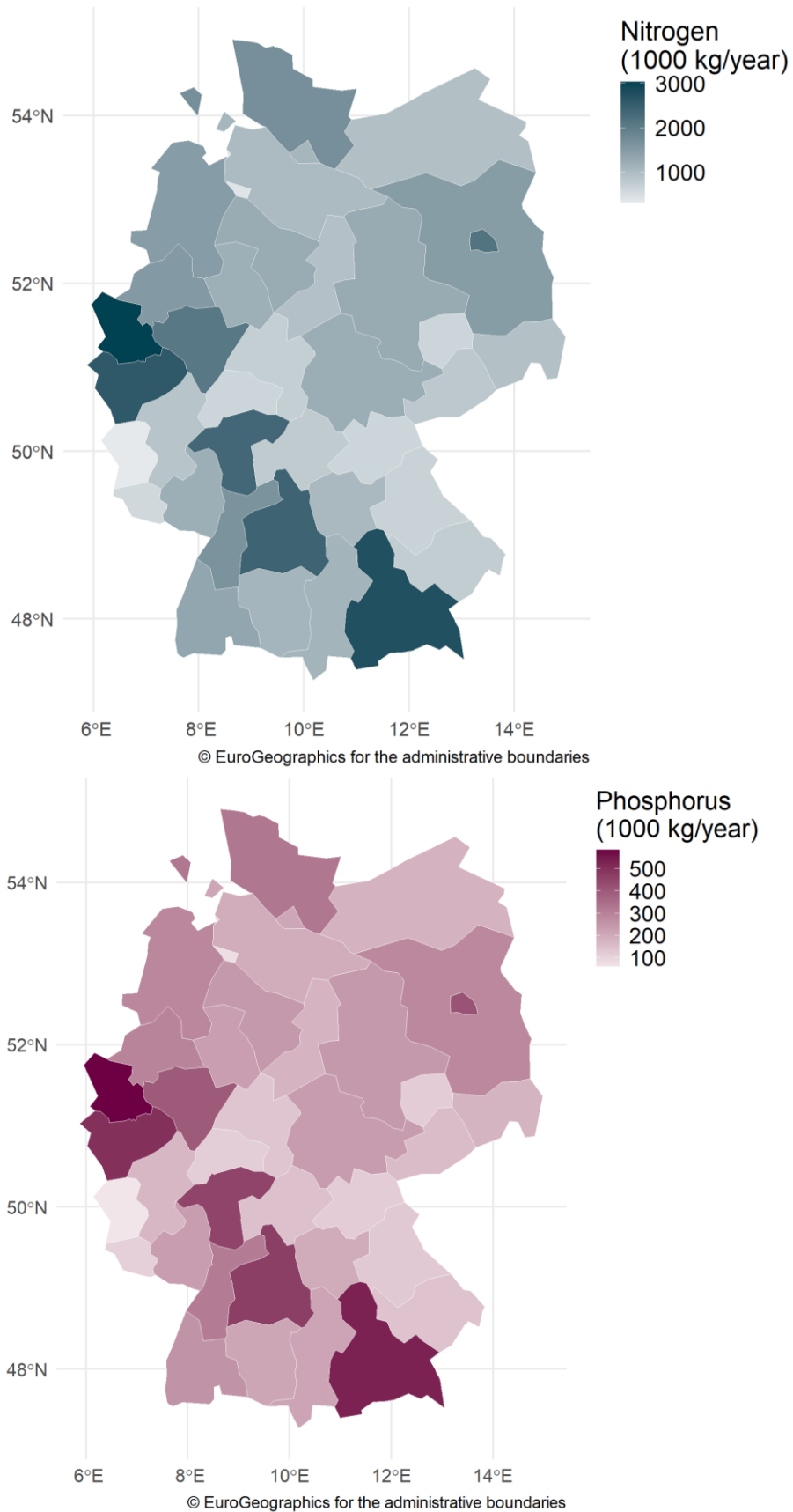


Figure 37. Spatial distribution of nitrogen (above) and phosphorus (below) in municipal bio-waste in Germany in 2023.

In comparison to the results calculated with the Eurostat method (Chapter 2), nitrogen content is significantly lower using the national data presented here (Table 49). The reason is the use of different nutrient contents for the biowaste altogether or in different sub-categories. The calculation using the Eurostat method is based on Banks et al. (2018) assuming higher nitrogen content.

Table 51. Comparison of results of calculations of the nutrient potential of biowastes for Germany (total) between Eurostat-base method and German national method.

	Amount (t/a)	N (t/a)	P (t/a)
Eurostat method	10.377.402	76.793	9.962
National German method	10.977.974	48.564	9.363
Difference	-600.572	28.229	599

The differences regarding the total amount of biowaste can also be attributed to different years for which the calculation was applied, i.e. population differed (2019 vs. 2023) and the different coefficient used. The Eurostat method uses the data of Favoino & Giavini (2020; 125 kg/person/a), while the national calculation divides the biowaste production to sub-categories as 56 kg/person/a of waste bin compost, 62.2 kg/person/a of garden and park waste and 11.9 kg/person/a of food waste from kitchens and canteens (130.1 kg/person/a) with the population data from 2022.

Sewage sludge

The production of sewage sludge also follows the population density resulting in total to nearly 1.8 million tons of dry matter, 68 457 tons of nitrogen and 46 231 tons of phosphorus (Table 52; Figure 38).

Table 52. Production and nutrient content in sewage sludge in Germany in 2023.

NUTS code and region	Municipal sewage sludge produced (t DM/year)	Nitrogen (t/a)	Phosphorus (t/a)
DE11 Stuttgart	88 650	3 413	2 305
DE12 Karlsruhe	60 038	2 311	1 561
DE13 Freiburg	48 957	1 885	1 273
DE14 Tübingen	40 118	1 545	1 043
DE21 Oberbayern	101 211	3 897	2 631
DE22 Niederbayern	26 852	1 034	698
DE23 Oberpfalz	23 897	920	621
DE24 Oberfranken	22 633	871	588
DE25 Mittelfranken	38 062	1 465	990
DE26 Unterfranken	28 126	1 083	731
DE27 Schwaben	41 017	1 579	1 066
DE3 Berlin	79 152	3 047	2 058
DE4 Brandenburg	54 236	2 088	1 410
DE5 Bremen	14 435	556	375
DE6 Hamburg	39 882	1 535	1 037
DE71 Darmstadt	86 168	3 317	2 240
DE72 Gießen	22 497	866	585
DE73 Kassel	26 050	1 003	677
DE8 Mecklenburg-Vorpommern	34 323	1 321	892
DE91 Braunschweig	33 953	1 307	883
DE92 Hannover	45 951	1 769	1 195
DE93 Lüneburg	37 037	1 426	963
DE94 Weser-Ems	54 637	2 104	1 421
DEA1 Düsseldorf	110 893	4 269	2 883
DEA2 Köln	95 432	3 674	2 481
DEA3 Münster	56 157	2 162	1 460
DEA4 Detmold	43 954	1 692	1 143
DEA5 Arnberg	75 896	2 922	1 973
DEB1 Koblenz	32 091	1 236	834
DEB2 Trier	11 520	444	300
DEB3 Rheinhessen-Pfalz	44 054	1 696	1 145
DEC Saarland	20 923	806	544
DED2 Dresden	33 688	1 297	876
DED4 Chemnitz	29 752	1 145	774
DED5 Leipzig	22 687	873	590
DEE Sachsen-Anhalt	46 090	1 774	1 198
DEF Schleswig-Holstein	62 248	2 397	1 618
DEG Thüringen	44 829	1 726	1 166
DE Germany (total)	1 778 096	68 457	46 231

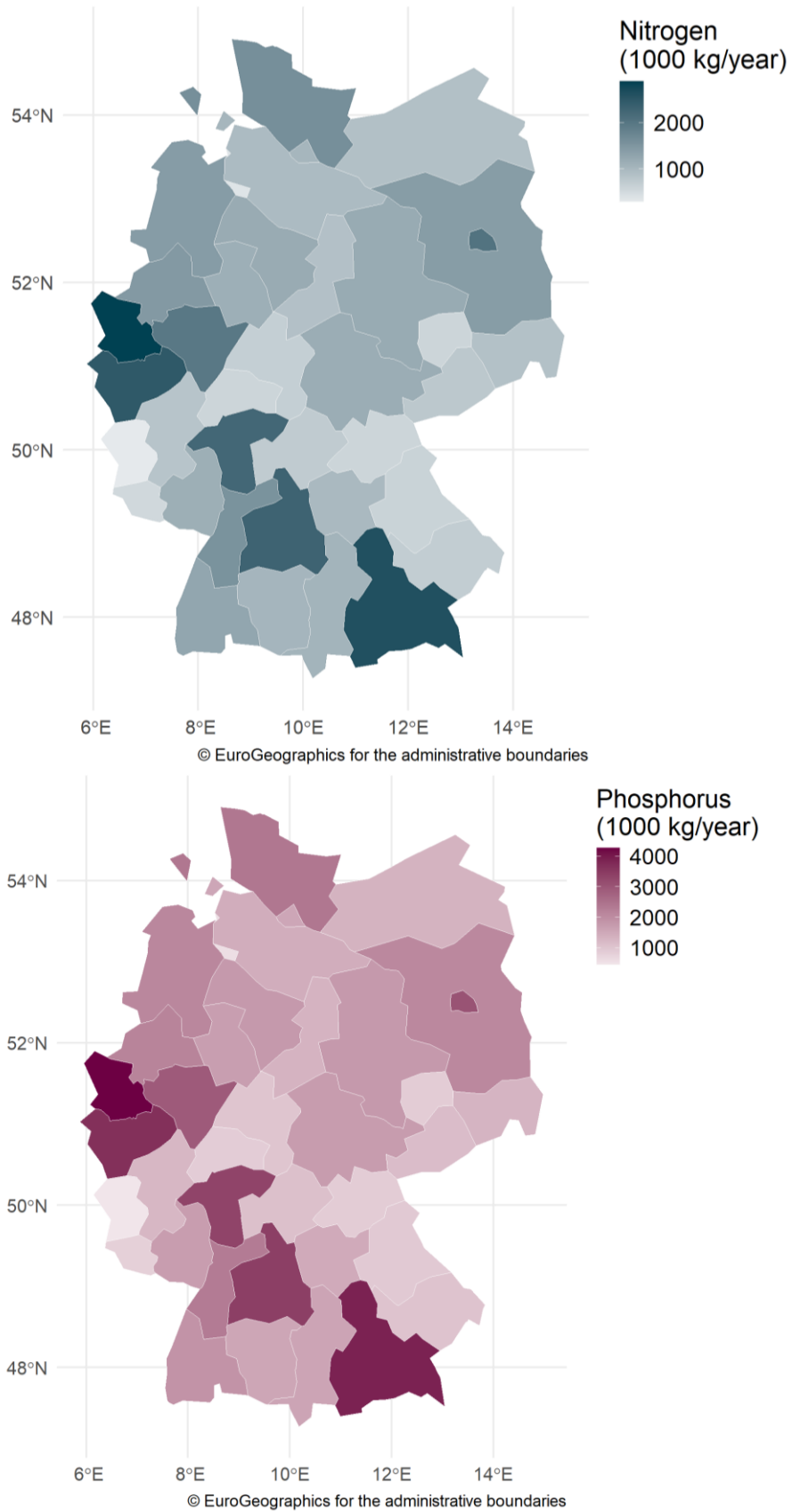


Figure 38. Spatial distribution of nitrogen (above) and phosphorus (below) in sewage sludge in Germany in 2023.

Industrial side streams

The industrial side streams included into this report are animal by-products (slaughtering waste; Table 53), brewer’s spent grain (Table 54), whey (Table 55) and grape pomace (Table 56).

Table 53. Production and nutrient content in animal by-products (slaughtering wastes) in Germany in 2022 (poultry) and 2023 (pig, cattle, sheep, goat).

Species	Animals slaughtered (heads)	Waste proportion (kg/animal)	Slaughtering waste (t/a)	Average N (%)	Average P (%)	Nitrogen (t/a)	Phosphorus (t/a)
Pig	47 113 500	26	1 224 951	2.5	0.56	30 624	6 860
Cattle	2 998 400	180	539 712	2.9	0.7	15 652	3 778
Poultry	701 497 000	0.77	540 153	2.8	0.58	15 124	3 133
Sheep	23 200	2.5	58	2.4	0.6	1.6	0.35
Goat	124 400	2.5	311	2.5	0.6	7.8	1.9
Total			2 305 185			61 409	13 773

Table 54. Production and nutrient content of brewer’s spent grain in Germany in 2023.

	Beer production (hl)	Amount of BSG (t/a)	Amount of BSG (t DM/a)	Nitrogen (t/a)	Phosphorus (t/a)
Alcoholic	72 415 318	1 448 306	362 077	14 483	2 172
Non-alcoholic and beer containing <= 0.5% alcohol	5 562 562	111 251	27 813	1 113	167
Total	77 977 880	1 559 558	389 889	15 596	2 339

Table 55. Production and nutrient content of whey in Germany in 2021.

	Amount FM (t/a)	Amount DM (t)	Nitrogen (t/a)	Phosphorus (t/a)
Sweet whey (80%)	13 162 056	789 723	17 058	5 370
Sour Whey (20%)	3 290 514	210 593	3 327	2 548
Whey (100%) (sour whey + sweet whey)	16 452 570	1 000 316	20 385	7 918

Table 56. Production and nutrient content of grape pomace in Germany in 2023.

Grapes for wine (t/a)	Grape pomace (t FM)	Grape pomace (t DM)	Nitrogen (t/a)	Phosphorus (t/a)
1 174 050	152 627	40 293	2 640	112.8

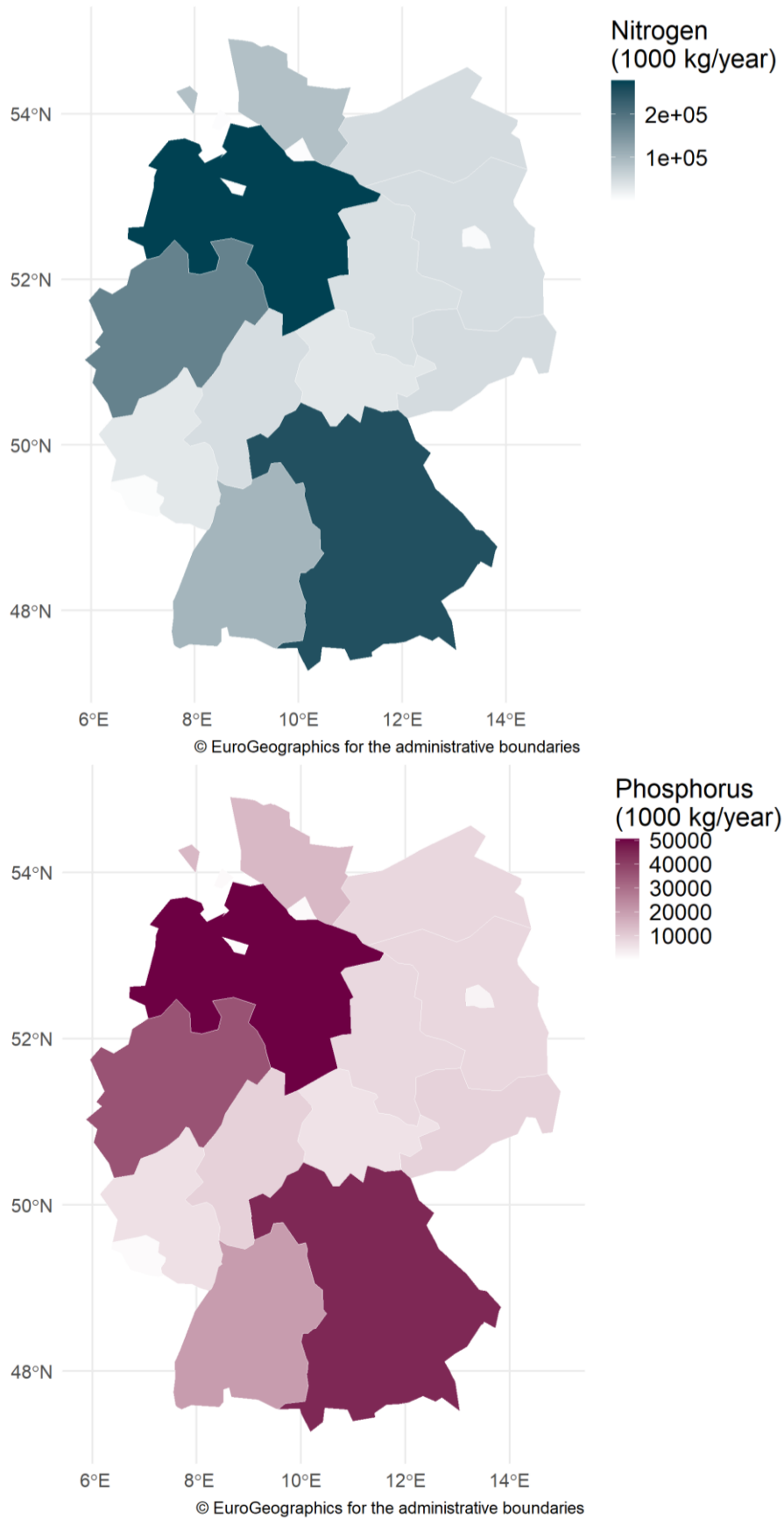


Figure 39. Spatial distribution of nitrogen (above) and phosphorus (below) of recyclable manure, sewage sludge and municipal biowaste in total in Germany.

References

- Banks, C.J., Heaven, S., Zhang, Y. & Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (red.) IEA Bioenergy Task 37, 2018:12.
- Benecke, C. 2022. Nachhaltige Verwertung von Wertstoffströmen: Gewinnung von Ethanol aus einem Reststoff der Molkeverarbeitung. Hannover: Gottfried Wilhelm Leibniz Universität, Diss., 2011, 114 S. <https://doi.org/10.15488/7587>
- Destatis 2023. Slaughtered animals, 2022 (GENESIS-Online data table 41322-0001). Accessed November 18, 2025, from <https://www-genesis.destatis.de/genesis/online>
- Destatis 2024a. Statistical Report – Waste Balance 2022. Tables 32171-06 / csv-32171-06. Published on 24 June 2024, corrected on 1 October 2024. GENESIS-Online. <https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfall-wirtschaft/Publikationen/Downloads-Abfallwirtschaft/statistischer-bericht-abfallbilanz-5321001227005.xlsx? blob=publicationFile>
- Destatis 2024b. Gewerbliche Schlachtungen – 2023. Accessed November 18, 2025: <https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Tiere-Tierische-Erzeugung/Tabellen/gewerbliche-schlachtung-jahr-halbjahr.html>
- DüV 2017 German Fertiliser Ordinance of 26 May 2017. Federal Law Gazette I, p. 1305. https://www.gesetze-im-internet.de/d_mv_2012/D%C3%BCMV.pdf
- EC 2010. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part III: Project Interim Reports. <https://op.europa.eu/mt/publication-detail/-/publication/68de0e64-01a4-11ec-8f47-01aa75ed71a1/language-en>
- Favoino, E. & Giavini, M. 2020. Bio-waste generation in the EU: Current capture levels and future potential- Bio-based Industries Consortium (BIC). 50 pp. https://zerowaste-europe.eu/wpcontent/uploads/2020/07/2020_07_06_bic_zwe_report_bio_waste_en.pdf
- Ferrer, J., Páez, G., Mármol, Z., Ramones, E., Chandler, C., Marín, M. & Ferrer, A. 2001. Agronomic use of biotechnologically processed grape wastes. *Bioresource Technology* 76: 39-44. [https://doi.org/10.1016/S0960-8524\(00\)00076-6](https://doi.org/10.1016/S0960-8524(00)00076-6)
- Finnish Environment Institute 2000. Finnish Expert Report on Best Available Techniques in Slaughterhouses and Installations for the disposal or recycling of animal carcasses and animal waste. *The Finnish Environment* 539. 42 pp. <http://hdl.handle.net/10138/40549>
- Luostarinen, S. Lehtonen, E., Skyttä, A., Seppänen, A.-M. & Tampio, E. 2021. Dataset of regional NRSS available for producing BBFs in the EU. Deliverable 1.1-D5_WP1. Project LEX4BIO. https://lex4bio.eu/wp-content/uploads/2022/09/LEX4BIO_D1.1_WP1-1.pdf
- Mozhiarasi, V. & Natarajan, T.S. 2022. Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added products. *Biomass Conv. Bioref.* 15: 1705–1728 (2025). <https://doi.org/10.1007/s13399-022-02352-0>

- Möller, K. & Schultheiss, U. 2014. Organische Handelsdüngemittel im ökologischen Landbau. Charakterisierung und Empfehlungen für die Praxis. KTBL-Schrift 499, Darmstadt.
- Oliveira, M. & Duarte, E. 2016. Integrated approach to winery waste: waste generation and data consolidation. *Front. Environ. Sci. Eng.* 10, 168–176.
<https://doi.org/10.1007/s11783-014-0693-6>
- Schaffner S., Wolf, G. & Kawasch, M. 2011. Rüben als Biogassubstrat – Teil 1/2 - Überblick über Verfahrenswege zu Transport und Aufbereitung. In: *Biogas Forum Bayern*. Nr. II – 17/2011. <https://www.biogas-forum-bayern.de/media/files/0004/r-ben-als-biogassubstrat-1.pdf>
- Schönberger, H. 2010. Organische Dünger richtig bewerten. *Top agrar* 7/2010: 58–63.
<https://www.topagrar.com/acker/aus-dem-heft/organische-duenger-richtig-bewerten-9692210.html>
- Schulze-Lammers, P. & Roller O. 2010. Entblattung von Zuckerrüben - Bewertung der Arbeitsqualität und des Mehrertrags. *Agricultural engineering.Eu*, 65(6): 464–467.
<https://doi.org/10.15150/lt.2010.550>
- StoffBiIV 2017. German Fertiliser Balancing Ordinance of 26 May 2017. *Federal Law Gazette I*, p. 1305. <https://www.recht.bund.de/bgbl/1/2025/155/VO.html>

3.7. Sweden

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Sweden is administratively divided into NUTS regions on different levels (Figure 40). The regions vary significantly in agricultural intensity, livestock density, and the generation of organic waste streams.

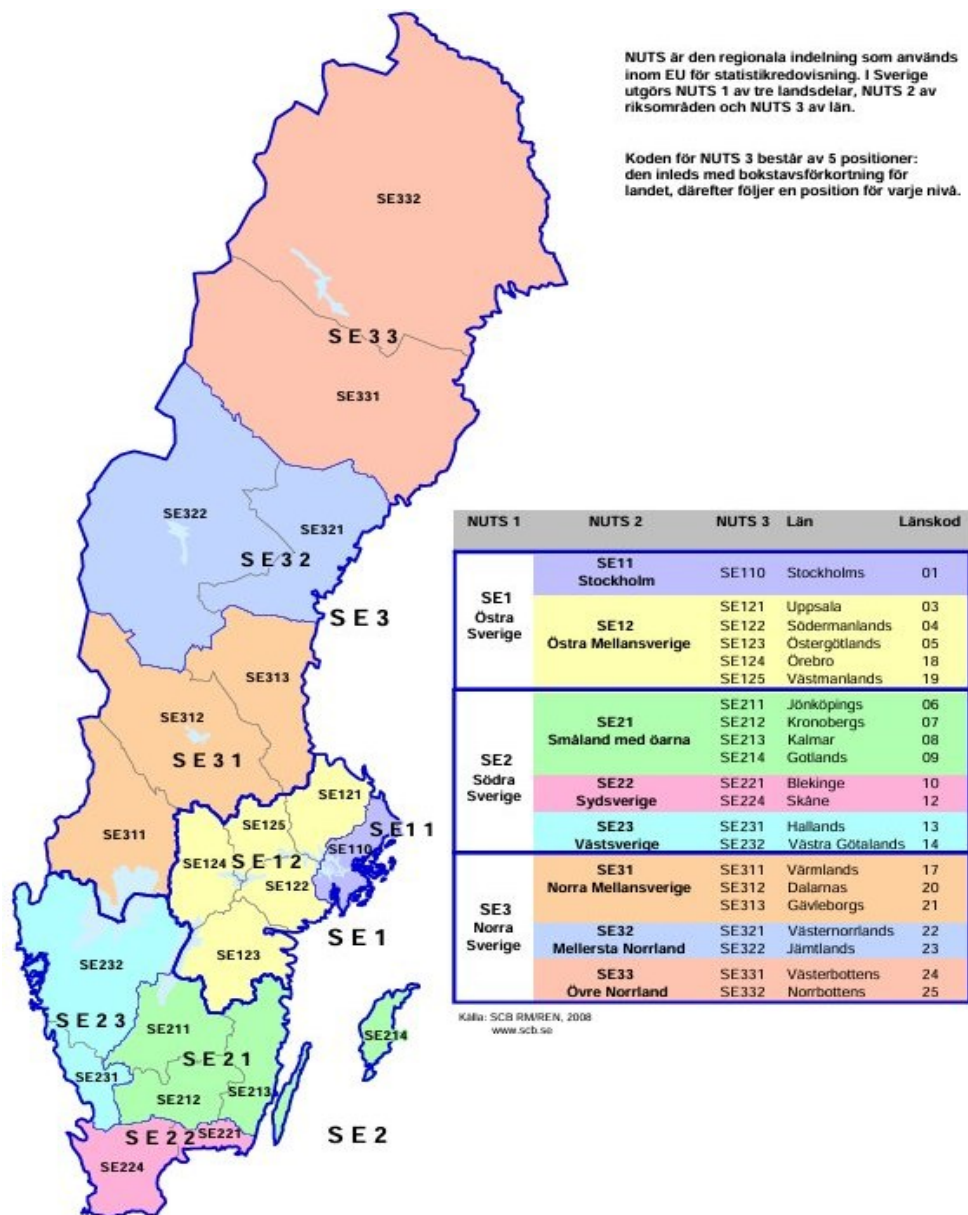


Figure 40. NUTS statistical regions of Sweden: Stockholm (SE01), East Middle Sweden (SE02), South Sweden (SE04), North Middle Sweden (SE06), Middle Norrland (SE07), Upper Norrland (SE08), Småland and the islands (SE09), and West Sweden (SE0A; Region Kronoberg 2015).

Livestock farming is a major contributor to nutrient recycling potential in Sweden, with significant numbers of cattle, pigs, poultry, and sheep. Additionally, Sweden's municipal waste management system produces substantial amounts of sewage sludge and biowaste, both rich in nitrogen (N) and phosphorus (P).

3.7.1. Materials and methods

The analysis of nutrient recycling potential in Sweden utilized data from multiple sources, including:

- EUROSTAT Database (2020): Providing regional livestock data and waste statistics.
- Swedish Agricultural Agency (2023): Detailing manure production volumes and nutrient compositions.
- Scientific Reports and Assumptions: Standard nutrient content values for livestock manure, municipal sludge, and biowaste.

The study focused on key nutrient-rich waste streams:

1. Livestock manure: Quantified using average manure production rates per animal type and adjusted for nitrogen and phosphorus content.
2. Municipal sewage sludge and biowaste: Sourced from wastewater treatment plants and organic waste collection systems, with nutrient contents based on standardized values.
3. Industrial by-products: Including organic waste from food processing industries and slaughterhouses.

Livestock Manure

The number of cattle, pigs, poultry and sheep (2023) and horses (2016) are from the statistics of Swedish Board of Agriculture (Jordbruksverket 2023) and the number of minks (fur animals) from Swedish Mink Association (2023, Table 56).

Table 57. Number of animals per NUTS regions in Sweden.

Region	NUTS_ID	Cattle ¹	Pigs ¹	Poultry ¹	Horses ²	Sheep ¹	Fur animal (minks) ³
Sweden	SE	1 444 483	1 303 503	35 181 696	355 500	486 082	150 000
Stockholm	SE11	15 602	12 086	35 519	27 400	15 411	
Östra Mellansverige	SE12	238 357	262 183	10 834 727	62 300	97 579	
Uppsala	SE121	40 290	21 658	121 627	16 600	16 794	
Södermanlands	SE122	40 823	54 299	4 120 546	8 400	18 182	
Östergötlands	SE123	104 560	79 684	4 116 622	15 500	37 040	
Örebro	SE124	31 885	58 955	1 583 114	11 900	16 145	
Västmanlands	SE125	20 799	47 587	892 818	9 900	9 418	
Småland med öarna	SE21	389 329	115 680	7 718 514	53 300	137 019	
Jönköpings	SE211	124 568	4 185	188 697	18 900	26 564	
Kronobergs	SE212	62 468	12 907	931 530	13 800	17 728	
Kalmar	SE213	144 186	60 955	6 388 689	14 700	33 245	
Gotlands	SE214	58 107	37 633	209 598	5 900	59 482	
Sydsverige	SE22	233 789	424 085	7 461 327	65 500	69 601	
Blekinge	SE221	25 277	29 306	2 362 566	7 400	14 497	
Skåne	SE224	208 512	394 779	5 098 761	58 100	55 104	
Västsverige	SE23	341 696	400 568	7 961 814	75 000	91 483	
Hallands	SE231	85 404	119 090	1 575 614	18 600	24 043	
Västra Götalands	SE232	256 292	281 478	6 386 200	56 400	67 440	
Norra Mellansverige	SE31	118 732	61 294	315 858	42 400	44 314	
Värmlands	SE311	47 207	47 587	200 676	11 900	15 958	
Dalarnas	SE312	30 091	5 444	39 167	18 800	14 515	
Gävleborg	SE313	41 434	8 263	76 015	11 700	13 841	
Mellersta Norrland	SE32	56 506	4 516	75 290	14 200	15 382	
Västernorrlands	SE321	26 404	4 058	64 018	7 200	7 205	
Jämtlands	SE322	30 102	458	11 272	7 000	8 177	
Övre Norrland	SE33	50 472	29 027	127 206	15 400	15 293	
Västerbottens	SE331	35 107	10 979	86 663	9 700	9 195	
Norrbottens	SE332	15 365	18 048	40 543	5 700	6 098	
SUM		1 428 881	1 297 353	34 494 736	328 100	470 671	

Source: ¹ Jordbruksverket (2023), ² Jordbruksverket (2016), ³Swedish Mink Association (2023).

To calculate the annual manure production in Sweden's various regions, the number of animals in each group (Table 56) is multiplied by the estimated manure output per group (expressed in tonnes per year, Table 57). Additionally, the nitrogen (N) and phosphorus (P) content of the manure are factored in to determine the nutrient contributions from each animal group.

Table 58. Coefficients used for each animal group to calculate the mass, nitrogen and phosphorus contents based on the number of animals.

Animal Group	Mass (t/animal/a)	N excretion	P excretion
Cattle slurry	12	71.6	9.2
Cattle solid manure	50% of slurry	0.005	0.0015
Cattle urine	50% of slurry	0.0075	0.00025
Pig slurry	1.5	12.4	2.4
Pig solid manure	25% of slurry	0.006	0.0015
Pig urine	75% of slurry	0.0075	0.00005
Poultry manure	0.0493	0.02	0.0075
Horse manure	17.5	0.0073	0.0014
Sheep and goat manure	1.004	0.0085	0.00325
Fur animal manure	0.0025	0.0135	0.0055

For livestock manure, the nutrient coefficients (Table 63) are based on the German data used in the Eurostat method (Chapter 2) and data from Swedish Board of Agriculture (Jordbruksverket), which align with typical nutrient content values observed in manure studies across Europe. These values reflect the nutrient composition of fresh matter (FM) in cattle, pigs, poultry, and sheep/goat manure, adjusted for regional agricultural practices.

Municipal waste streams

The nutrient content of municipal sewage sludge and source-separated biowaste was estimated based on established nutrient concentration values and waste production volumes for each waste stream. The approach considered variations in N and P content depending on the type of waste, processing methods, and regional factors. The calculated nutrient contents for municipal wastewater sewage sludge and biowaste are aggregated by NUTS regions, providing a regional breakdown of nutrient availability.

Sewage sludge

The data sources used are the national statistics (SCB 2020) for sludge production volumes and literature and national guidelines for nutrient recovery for average in treated sewage sludge. It is assumed that the nitrogen content in sewage sludge is 3.85% dry weight and phosphorus content 2.6% dry weight, reflecting the contribution from human excreta and food waste fractions. The total dry weight of sludge produced annually is multiplied by the assumed nutrient content percentages to estimate the recoverable nitrogen and phosphorus. Adjustments were made based on the recovery efficiency of downstream processes, such as struvite precipitation or direct land application.

Municipal biowaste

Volume of biowaste collected annually are based on the statistics from EUROSTAT (2020). Nutrient content is based on average compositions of food waste and organic residues. For general organic waste, the nutrient content was assumed to be 0.74% of wet weight, phosphorus content 0.4% of wet weight and dry matter (DM) content 24%. These values reflect typical ranges observed in pre-processed or untreated food waste and are adjusted for regional variations where available. The total mass of biowaste collected annually (wet weight) is then multiplied by the assumed nutrient content to estimate total nitrogen and phosphorus contributions.

Industrial Waste Streams

The nutrient content of industrial waste streams, including animal by-products and food industry side-streams, is estimated based on production volumes and standard nutrient concentration values. Calculations are performed for the country of Sweden as the analysis for the NUTS regions was not available for these streams.

Data on animal by-products are obtained from the Swedish Board of Agriculture (Jordbruksverket 2022), based on the total number of animals slaughtered in 2022. For each animal category, the proportion of the carcass classified as waste is estimated as follows: 50% for cattle, 35% for pigs, 30% for poultry, and 50% for sheep and goats. It is further assumed that 70% of the waste is fresh matter (FM), and nutrient content coefficients for nitrogen (N) and phosphorus (P) applied to the fresh matter are as follows:

- Cattle: 2.9% FM N, 0.7% FM P
- Pigs: 2.5% FM N, 0.56% FM P
- Poultry: 2.8% FM N, 0.58% FM P
- Sheep and Goats: 2.8% FM N, 0.58% FM P

Production volumes for food industry side-streams are gathered from processing facilities and national food waste reports. This includes wastes from vegetable processing, dairy production, and bakeries. The nutrient contents are considered as 1.5% N and 0.3% P in FM.

3.7.2. Nutrient recycling potential in Sweden

The analysis revealed significant nutrient recycling potential from Sweden's organic waste streams (Table 58).

Table 59. The amount and nutrient content of different recyclable biomasses in Sweden.

	Mass (t/a)	Ntot (t/a)	Ptot (t/a)
Livestock manure	43 079 197	297 427	50 260
Municipal biowaste	1 091 626	8 078	1 048
Sewage sludge	208 348*	8 021	5 417
Animal by-products	31 165	609	127
Industrial side streams	12	0.18	0.036
Total		314 135	56 852

*(tDM/a)

The total annual manure production was estimated at 17.33 million tonnes from cattle, 1.96 million tonnes from pigs, and 1.73 million tonnes from poultry (Tables 60-62). The manure could yield approximately 47 000 tonnes of nitrogen and 7 000 tonnes of phosphorus annually, with regional variations reflecting livestock densities across Swedish regions (Figure 41). The results highlight regions like Småland and the Islands, South Sweden, and West Sweden as key areas of manure production due to their high livestock populations.

Table 60. Production and nutrient content of livestock manure as cattle slurry, solid manure, and urine in Sweden in 2023.

Region	NUTS_ID	Cattle slurry			Cattle solid manures			Cattle urine		
		Mass, t/a	N, t/a	P, t/a	Mass	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a
Sweden	SE	17 330 880	103 473	13 277	8 665 440	43 327	12 998	8 665 440	64 991	2 166
Stockholm	SE11	187 224	1 118	143	93 612	468	140	93 612	702	23
Östra Mellansverige	SE12	2 860 284	17 074	2 191	1 430 142	7 151	2 145	1 430 142	10 726	358
Småland med öarna	SE21	4 670 748	27 889	3 579	2 335 374	11 677	3 503	2 335 374	17 515	584
Sydsverige	SE22	2 805 468	16 747	2 149	1 402 734	7 014	2 104	1 402 734	10 521	351
Västsverige	SE23	4 100 352	24 477	3 141	2 050 176	10 251	3 075	2 050 176	15 376	512
Norra Mellansverige	SE31	1 424 784	8 505	1 091	712 392	3 562	1 069	712 392	5 343	178
Mellersta Norrland	SE32	678 072	4 048	519	339 036	1 695	509	339 036	2 543	85
Övre Norrland	SE33	605 664	3 615	464	302 832	1 514	454	302 832	2 271	76

Table 61. Production and nutrient content of livestock manure as pig slurry, solid manure, and urine in Sweden in 2023.

Region	NUTS_ID	Pig slurry			Pig solid manures			Pig urine		
		Mass, t/a	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a
Sweden	SE	1 955 255	16 131	3 144	488 814	2 933	733	1 466 441	10 998	73
Stockholm	SE11	18 129	150	29	4 532	27	6.8	13 597	102	0.68
Östra Mellansverige	SE12	393 274	3 244	632	98 319	590	148	294 956	2 212	15
Småland med öarna	SE21	173 520	1 431	279	43 380	260	65	130 140	976	6.5
Sydsverige	SE22	636 127	5 248	1 023	159 032	954	239	477 096	3 578	24
Västsverige	SE23	600 852	4 957	966	150 213	901	225	450 639	3 380	23
Norra Mellansverige	SE31	91 941	758	148	22 985	138	34	68 956	517	3.5
Mellersta Norrland	SE32	6 774	56	11	1 693	10	2.5	5 080	38	0.25
Övre Norrland	SE33	43 541	359	70	10 885	65	16	32 655	245	1.6

Table 62. Production and nutrient content of livestock manure as manure for poultry, horse, sheep and goat and fur animal in Sweden in 2023.

Region	NUTS_ID	Poultry manure			Horse manure			Sheep and goat manure			Fur animal manure		
		Mass, t/a	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a	Mass, t/a	N, t/a	P, t/a
Sweden	SE	1 734 458	34 689	13 008	2 270 756	16 552	3 200	488 026	4 148	1 586	13 687	185	75
Stockholm	SE11	1 751	35	13	175 017	1 276	247	15 473	132	50			
Östra Mellansverige	SE12	534 152	10 683	4 006	397 941	2 901	561	97 969	833	318			
Småland med öarna	SE21	380 523	7 610	2 854	340 454	2 482	480	137 567	1 169	447			
Sydsverige	SE22	367 843	7 357	2 759	418 381	3 050	590	69 879	594	227			
Västsverige	SE23	392 517	7 850	2 944	479 062	3 492	675	91 849	781	299			
Norra Mellansverige	SE31	15 572	311	115	270 830	1 974	382	44 491	378	145			
Mellersta Norrland	SE32	3 712	74	28	90 703	661	128	15 443	131	50			
Övre Norrland	SE33	6 271	125	47	98 367	717	139	15 354	131	50			

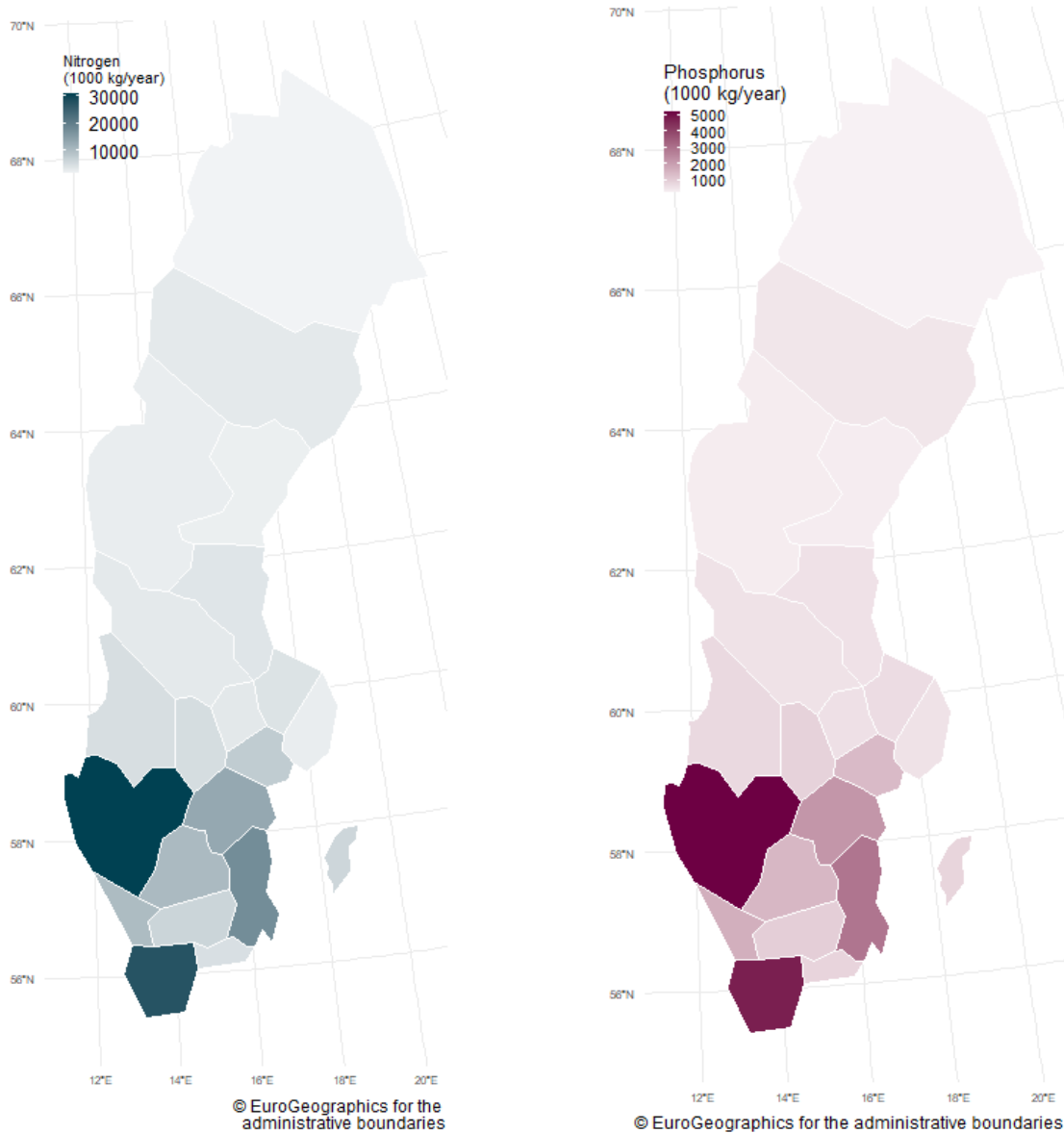


Figure 41. Spatial distribution of nitrogen (left) and phosphorus (right) in livestock manure (including cattle, pigs, poultry, horses, sheep and goats) in Sweden in 2023.

Municipal sewage sludge and source-separated biowaste also contribute significantly to nutrient recycling potential as shown in Table 63. Annually, approximately 208 000 tonnes of dry matter in sewage sludge are produced, containing an estimated 8 021 tonnes of nitrogen and 5 417 tonnes of phosphorus. Source-separated biowaste contributes an additional 1.09 million tonnes of fresh matter, yielding 8 078 tonnes of nitrogen and 1 048 tonnes of phosphorus. These nutrient-rich waste streams are essential for supplementing agricultural needs while reducing nutrient runoff into aquatic ecosystems.

Regions with high population densities, such as Stockholm, South Sweden, and West Sweden, generate the largest volumes of municipal waste streams, reflecting the role of urban centers in nutrient recycling (Figures 42 & 43). The potential for nutrient recovery from these streams highlights the importance of integrating municipal waste management systems into broader nutrient recycling strategies.

Table 63. The production and nutrient content of municipal waste streams, broken down by region, in Sweden.

Region	NUTS_ID	Municipal sewage sludge			Municipal source-separated biowaste		
		Mass (DM), t/a	N, t/a	P, t/a	Mass (FM), t/a	N, t/a	P, t/a
Sweden	SE	208 348	8 021	5 417	1 091 626	8 078	1 048
Stockholm	SE11	40 183	1 547	1 045	251 257	1 859	241
Östra Mellansverige	SE12	34 669	1 335	901	182 586	1 351	175
Uppsala	SE121	6 454	248.48	167.80			
Södermanlands	SE122	6 448	248.25	167.65			
Östergötlands	SE123	9 066	349.04	235.72			
Örebro	SE124	7 188	276.74	186.89			
Västmanlands	SE125	5 513	212.25	143.34			
Småland med öarna	SE21	22 203	855	577	91 980	681	88.3
Jönköpings	SE211	7 151	275.31	185.93			
Kronobergs	SE212	4 498	173.17	116.95			
Kalmar	SE213	9 588	369.14	249.29			
Gotlands	SE214	966	37.19	25.12			
Sydsverige	SE22	31 585	1 216	821	162 507	1 203	156
Blekinge	SE221	4 193	161.43	109.02			
Skåne	SE224	27 392	1054.59	712.19			
Västsverige	SE23	41 266	1 589	1 073	217 713	1 611	209
Hallands	SE231	8 315	320.13	216.19			
Västra Götalands	SE232	32 951	1268.61	856.73			
Norra Mellansverige	SE31	18 872	727	491	90 665	671	87
Värmlands	SE311	5 800	223.30	150.80			
Dalarnas	SE312	7 703	296.57	200.28			
Gävleborg	SE313	5 369	206.71	139.59			
Mellersta Norrland	SE32	6 282	242	163	39 760	294	38
Västernorrlands	SE321	4 695	180.76	122.07			
Jämtlands	SE322	1 587	61.10	41.26			
Övre Norrland	SE33	13 290	512	345	55 157	408	52.9
Västerbottens	SE331	6 393	246.13	166.22			
Norrbottnens	SE332	6 897	265.53	179.32			

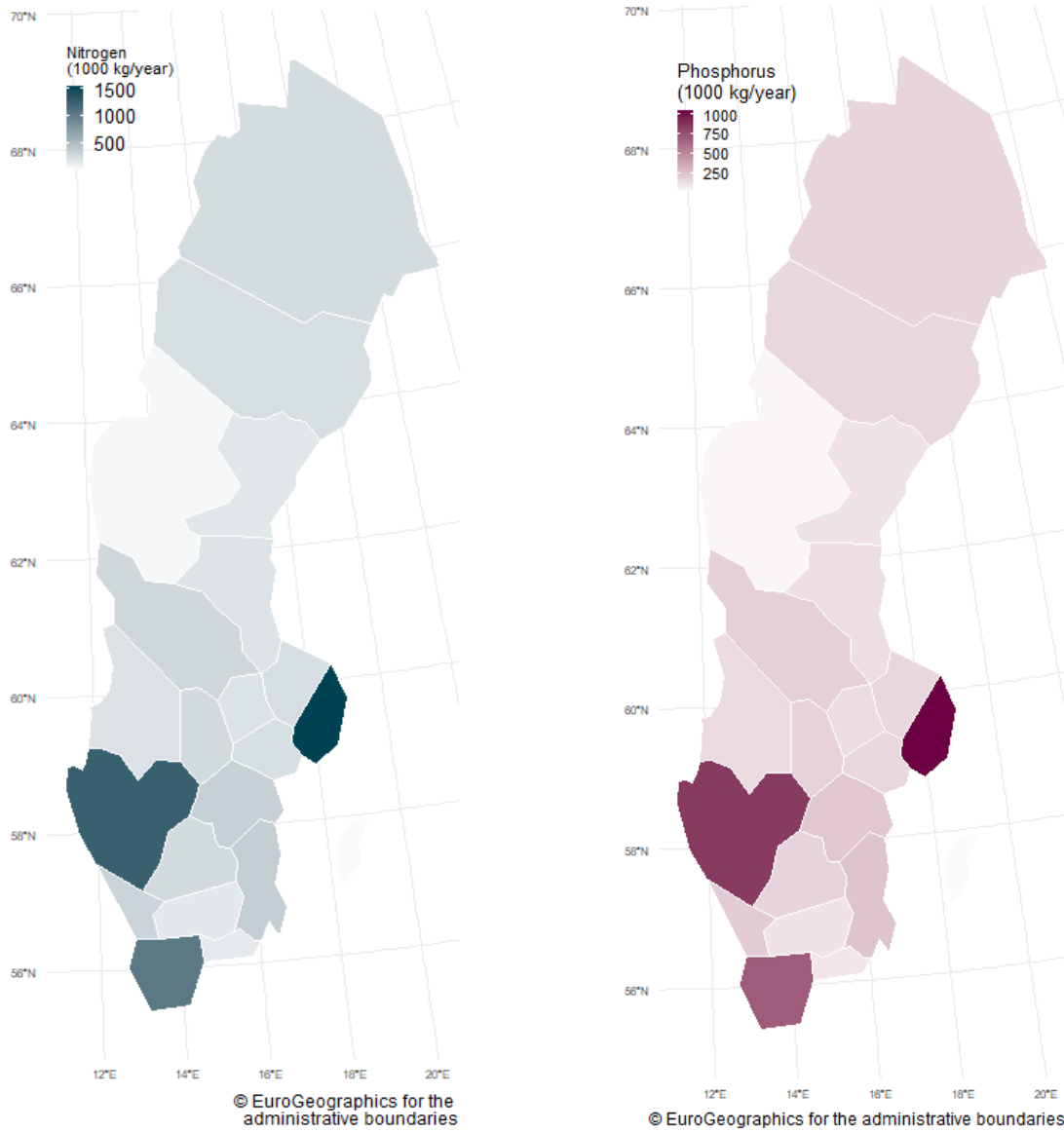


Figure 42. Spatial distribution of nitrogen (left) and phosphorus (right) in sewage sludge in Sweden in 2023.

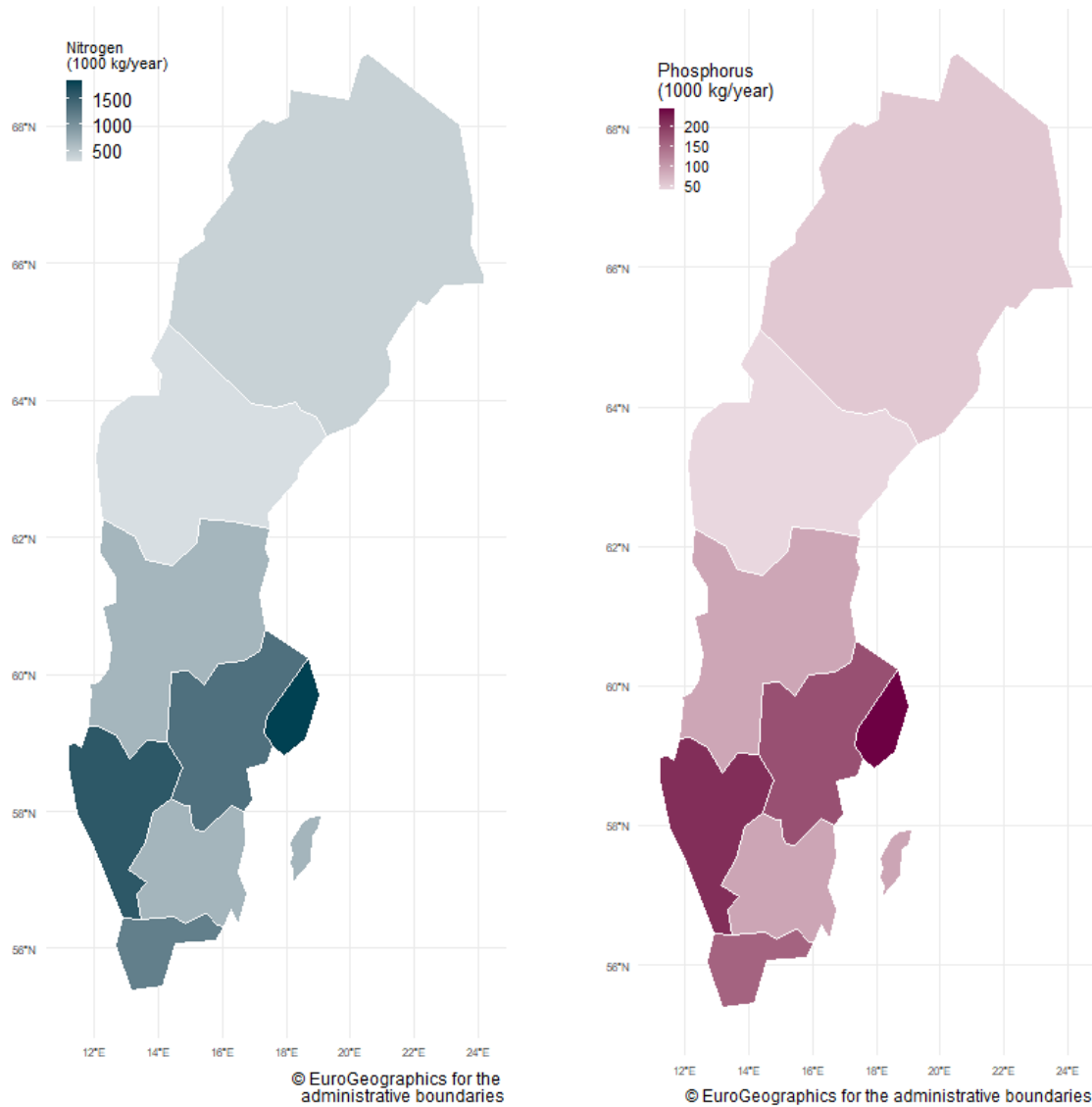


Figure 43. Spatial distribution of nitrogen (left) and phosphorus (right) in municipal source-separated biowaste in Sweden in 2023.

Recyclable nitrogen and phosphorus in manure, municipal biowaste and sewage sludge in total are shown in Figure 44.

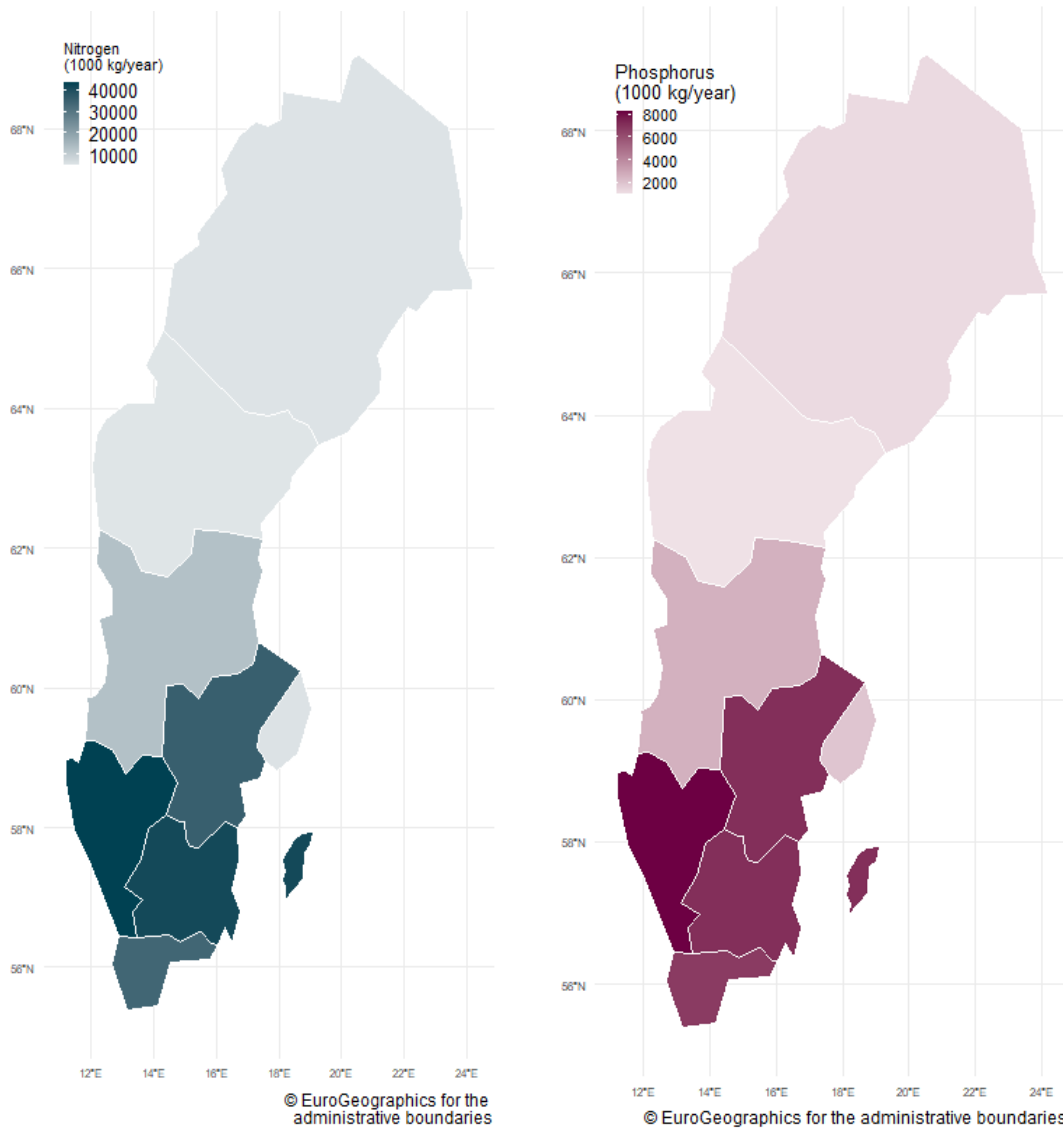


Figure 44. Spatial distribution of nitrogen (left) and phosphorus (right) in manure, sewage sludge and source separated biowaste in Sweden in 2023.

Industrial waste streams, including animal by-products and food industry side-streams, provide additional sources of recyclable nutrients. Annually, 31 165 tonnes of animal by-products are generated, containing approximately 609 tonnes of nitrogen and 127 tonnes of phosphorus. This includes contributions from slaughterhouses, where by-products like blood, bones, and offal are rich in nutrients. Food industry side-streams, though smaller in volume, also contribute with 12 tonnes of organic waste, yielding 0.18 tonnes of nitrogen and 0.036 tonnes of phosphorus. While these streams are smaller in scale compared to livestock manure and municipal waste, they represent a valuable resource for nutrient recovery. As regional data were unavailable for these streams, Table 64 shows the estimation for the entire country.

Table 64. Estimated nutrient content of industrial waste streams for Sweden.

Region	NUTS_ID	Animal by-products			Food industry side-streams		
		Mass	Nitrogen	Phosphorus	Mass	Nitrogen	Phosphorus
		t/a	t/a	t/a	t/a	t/a	t/a
Sweden	SE	31 165	609	127	12	0.18	0.036

3.7.3. Comparison to EUROSTAT data

The comparison between EUROSTAT data and national estimates for Sweden reveals notable differences in nutrient content assessments for various waste streams. These variations are primarily influenced by differences in data sources, methodologies, and assumptions used in the calculations. For example, the comparison between EUROSTAT estimates and national data for livestock manure in Sweden reveals significant discrepancies in reported volumes and nutrient content. These differences can be attributed to several key factors, the first being differences in animal categories included (Eurostat excludes horses and fur animals, which the national data collection includes). Also, the national estimates incorporate more detailed manure production coefficients per animal, reflecting updated regional livestock density data and refined assumptions about nutrient retention in manure. Furthermore, the nutrient content of municipal biowaste is lower in the Eurostat-based results suggesting that Swedish coefficients are higher than those used in the Eurostat-based method.

The comparison of animal by-products between Eurostat-based estimates and national data reveals a substantial difference with Eurostat-based method resulting in much higher amount of nutrients. This large difference is likely due to differences in waste categorization and data inclusion criteria. The data in Eurostat may incorporate a broader range of animal processing waste fractions, including rendered materials, blood, bones, and other slaughterhouse by-products, whereas the Swedish dataset may focus on specific waste streams that are more directly relevant to bio-based fertilizer production. The variation highlights the need for greater alignment in classification methods to ensure consistency in nutrient recovery assessments across different reporting systems.

The higher Swedish estimates for livestock manure and biowaste indicate that more localized data collection and refined methodologies are capturing a greater nutrient recovery potential than what is reflected in EUROSTAT's reporting. This suggests that national datasets may provide a more detailed and accurate assessment of these waste streams. In contrast, sewage sludge estimates are relatively well-aligned between Eurostat-based data and national data, with only minor discrepancies, likely due to updated treatment plant efficiencies or differences in reporting structures. However, the significant disparities in animal by-products highlight inconsistencies in classification systems, which could impact nutrient recovery policies and regulations. If different datasets categorize and account for these materials differently, it may create challenges for policymakers and industry stakeholders in designing effective nutrient recycling strategies. These discrepancies underscore the need for harmonized nutrient recycling data methodologies across different reporting systems. Improving data consistency and comparability between national and EU sources is essential for better decision-making, policy alignment, and sustainable nutrient management across the Baltic Sea Region and beyond.

References

- Eurostat 2020. Agricultural statistics database (livestock, crops, and production indices). European Commission. Retrieved from <https://ec.europa.eu/eurostat>
- Jordbruksverket 2016. Växtnäring i animalieproduktion – beräkning av näringsflöden och regionala skillnader [Nutrient flows in animal production – calculation of nutrient flows and regional differences]. Swedish Board of Agriculture.
- Jordbruksverket 2022. Jordbruksstatistisk sammanställning 2022 [Swedish agricultural statistics compilation 2022]. Swedish Board of Agriculture. Retrieved from <https://jordbruksverket.se>
- Jordbruksverket 2023. Animalieproduktion och gödselhantering i Sverige 2023 [Animal production and manure management in Sweden 2023]. Swedish Board of Agriculture. Retrieved from <https://jordbruksverket.se>
- SBC 2020. Statistics on animal production in Sweden 2020. Statistics Sweden (Statistiska centralbyrån). Retrieved from <https://www.scb.se>
- Swedish Agricultural Agency 2023. Livestock numbers and nutrient balances 2023. Swedish Board of Agriculture.
- Swedish Mink Association. 2023 Annual report and production statistics 2023. Svenska Minkavelsföreningen.

4. Regions of surplus and deficit

Sari Luostarinen, Eeva Lehtonen, Elina Tampio & Johanna Laakso, Natural Resources Institute Finland (Luke)

The nutrient-rich biomasses (as estimated in chapters 2 and 3) are not evenly distributed within the BSR countries and their sub-regions. Agricultural wastes and side streams are located on farms and the concentration of production types can be seen from e.g. the spatial distribution of manure nutrients. Municipal wastes are located according to population density and industrial wastes and side streams according to the location of different industrial facilities. Thus, the information on the location of nutrient-rich biomasses and the amounts of nutrients contained in them is not sufficient to assess their availability for different uses, in this report mainly use as fertilizing products in agriculture.

A fairly simple way to connect the recyclable nutrients to the agricultural fertilization need is to compare the amount of nitrogen and phosphorus in the biomasses to the area of utilized agricultural area. The area is available in the Eurostat statistics (ef_lus_allcrops) in NUTS2 level. Thus, the latest data from year 2020 was used here in the comparison, and the comparison was made using the results of the Eurostat-method in chapter 2.

The result of the comparison is shown in Figure 45. The highest area-based amounts of recyclable nutrients (kg/ha) are in Denmark, Germany and Poland, while Sweden, Finland, Estonia, Latvia and Lithuania have lower amounts of recyclable nutrients per hectare of utilized agricultural area.

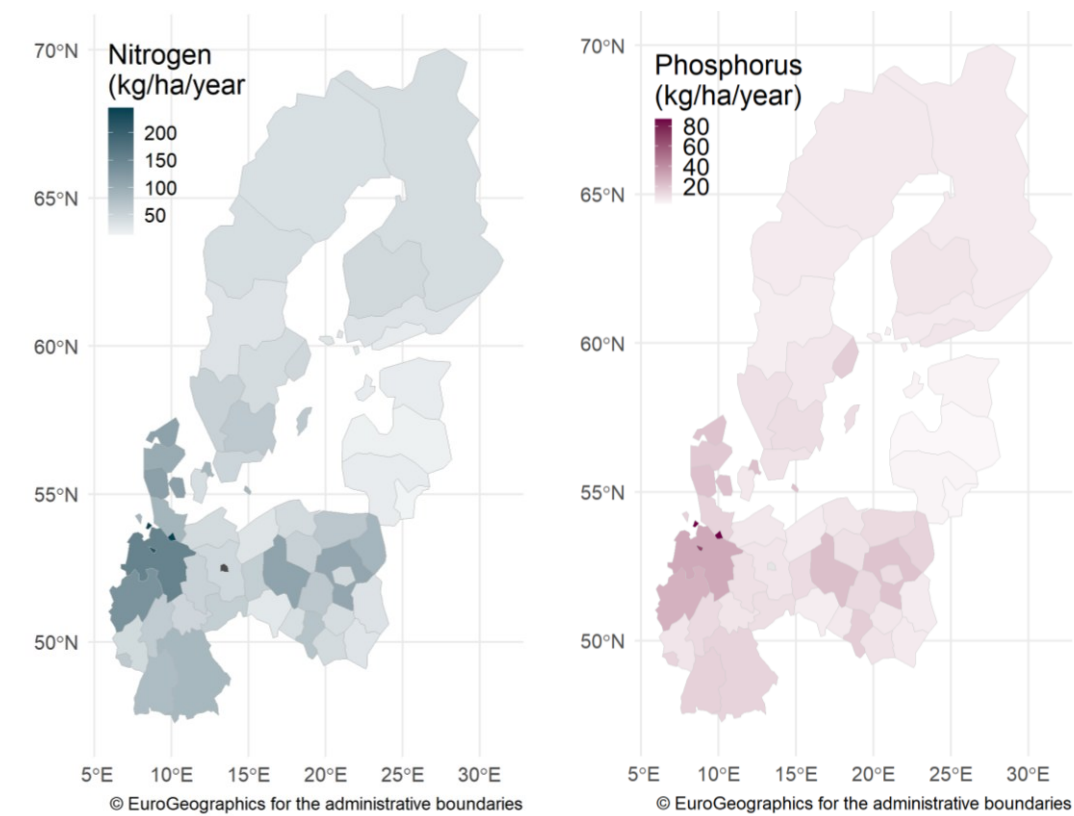


Figure 45. Nitrogen (left) and phosphorus (right) in the nutrient-rich biomasses (livestock manure, sewage sludge, municipal biowaste) collected with the Eurostat method (chapter 2) in comparison to utilized agricultural area as kilograms per hectare (kg/ha) in NUTS 2 level.

The comparison between the amount of recyclable nutrients and utilized agricultural area gives indication of potential areas of nutrient surplus and deficit. However, it fails to address the actual fertilization need which, in addition to field area, is affected by soil characteristics and plants produced. Moreover, the fertilization limits used in the calculation of fertilization need may differ depending on what information on plant nutrient need or which regulative fertilization limits are used. An important issue to note also is that the utilized agricultural area includes fields on which manure and many of the organic fertilizing products would not be applied, thus giving an overestimation of the field area available.

Therefore, a more detailed assessment of the extent to which recyclable nutrients in a given area suffice to the fertilization need of the same area should be conducted. This would properly identify regions of nutrient surplus and deficit and assist in planning and implementing nutrient recycling activities.

As the Eurostat data does not allow for such an analysis due to lack of some important datasets, such as soil characteristics, and the spatial resolution offered (NUTS2) is rather rough for many of the BSR countries, a more thorough assessment of the regions of surplus and deficit was not attempted in this project. This should be organized nationally using national statistics and other data sources. However, an example of such a national assessment is given in the following for Finland.

4.1. Example: Finland

Sari Luostarinen & Johanna Laakso, Natural Resources Institute Finland (Luke)

In Finland, the need for phosphorus fertilization in plant production is compared with the potentially available recycled phosphorus from biomasses at national, regional (ELY Centres, see: chapter 3.1), and municipality levels. The latest results have been published in Finnish by Lemola et al. (2023), from which the following has been adapted.

Material and methods

The parameters needed to compare the amount of recyclable phosphorus and phosphorus fertilization need in each region are soil phosphorus status, field area and yield of different crops cultivated, and the amount and phosphorus content of recyclable biomasses, i.e. manure, sewage sludge, industrial side streams, municipal biowaste, and other agricultural biomasses.

Since 1995, approximately 90% of Finland's arable land has been required to undergo regular (every five years) analysis of its readily soluble phosphorus content (soil phosphorus status), soil type and other parameters (organic matter content, conductivity, pH and potassium, calcium, and magnesium contents). Data on soil phosphorus status have been collected from laboratories that perform soil analyses. During the review periods, the number of analysis results varied between approximately 0.8 and 1 million, providing excellent coverage of the data. In the latest calculation, soil data from the period of 2015-2019 was used.

The crop areas used in the calculations were taken from the field parcel register maintained by Finnish Food Authority. The yields of the most important crops were obtained from the [statistical database](#) maintained by Natural Resources Institute Finland. The areas of grassland, cereals, and special crops were calculated from a database produced by Luke's statistical services. Sugar beet, potatoes, and open-field vegetables were counted as special crops.

The percentage of arable land in each municipality was calculated by dividing its arable land area by its total land area, as obtained from National Land Survey of Finland (2020). The arable land area was derived from municipality-specific statistics on agricultural land in use, which were produced by Luke's statistical services. This included cultivated land, fallow land, perennial garden plants and home gardens. The arable land area was then used to calculate the municipal arable land percentage, as well as the cultivated area, which is shown on maps describing plant and livestock production in Finland.

The data on animal numbers is based on the animal registry of Finnish Food Authority (year 2020 in this calculation). This data also includes information on the location of the animals. The number of horses in from 2018 (Hippos) and fur animals from 2021 (Fifur). Data on manure quantities and phosphorus contents are based on Finnish Normative Manure System (see: chapter 3.1), which calculates manure data for several different animal categories and five different types of manure. Other biomass data is collected from the national waste statistics, annual reports of fertilizing products, and the reporting system of companies producing side streams.

The regional need for phosphorus fertilization has been derived from the frequency distribution of soil types and soil phosphorus status in each region/municipality, as well as the crops grown in the area, which have been divided equally into all soil type/specific phosphorus distribution classes in the region under review. The annual need for phosphorus fertilization of cereals and grasslands has been found to end when the soil phosphorus value (using Finnish acidic ammonium acetate extraction) is above 6 mg/l for clay soils, above 10 mg/l for coarser mineral soils and above 15 mg/l for organic soils (Valkama et al. 2011, 2015). The annual phosphorus fertilization requirement for other crops was estimated based on various studies conducted in the Nordic countries. The phosphorus fertilization need in the area under review is then estimated, and the regional phosphorus surplus or deficit can be calculated as the difference between the phosphorus fertilization required by crops and the phosphorus in livestock manure and/or other recyclable biomasses.

Finland's phosphorus recycling potential and regions of manure phosphorus surpluses and deficits

Of Finland's phosphorus fertilization requirement, 65% could be met by phosphorus derived from manure according to the 2023 estimate. If distributed evenly, the phosphorus requirement for crop production on the country's approximately 2.3 million hectares of arable land would be slightly over 10 kg/ha. On average, the need for phosphorus supplementation would be less than 4 kg/ha, and the sales of mineral fertilizer phosphorus have been around 4.4 kg/ha (2022-23), but there are significant differences between regions in deficit and those with surpluses (Figure 46).

In Ostrobothnia, manure phosphorus is produced in quantities that far exceed crop requirements. Åland, Southwest Finland, Satakunta, and South Ostrobothnia would be almost self-sufficient in phosphorus, if manure phosphorus was distributed only to fields that benefit from phosphorus fertilization. However, there are significant differences within the administrative regions at the municipal level. Furthermore, it is important to note that in practice, manure is not spread evenly only on fields that need phosphorus fertilization, but as a rule, manure is spread on fields in the close vicinity of livestock farms. Local deficiencies and surpluses of phosphorus in manure are therefore significantly greater than suggested by the above analysis.

A previous investigation in 2014 estimated that manure phosphorus alone would be sufficient to completely cover the crops' phosphorus requirements (Ylivainio et al. 2014). However, since then, soil phosphorus status in fields has decreased and the number of hectares benefiting from annual phosphorus fertilization thus increased. At the same time, the phosphorus content of manure has fallen by around 10% since the study of Ylivainio et al. (2014) due to a decline in the number of livestock. Additionally, Ylivainio et al. (2014) only considered phosphorus fertilization requirements for cereals and grasslands, while the 2023 report included more precise fertilization requirements for different crops.

Despite differences in the amount of phosphorus in manure between regions, it appears that the sales of mineral phosphorus fertilizers are not related to the amount of manure produced in a given region. For instance, mineral fertilizer sales in areas with the largest manure phosphorus surpluses have not declined more sharply than the general trend. Regardless of regional concentrations of livestock production, farms specializing in livestock production often have more phosphorus in their manure than their crops require. Since most manure is used for local fertilization, processing manure nutrients into an easily transportable form should be developed in areas where local nutrient surpluses exist.

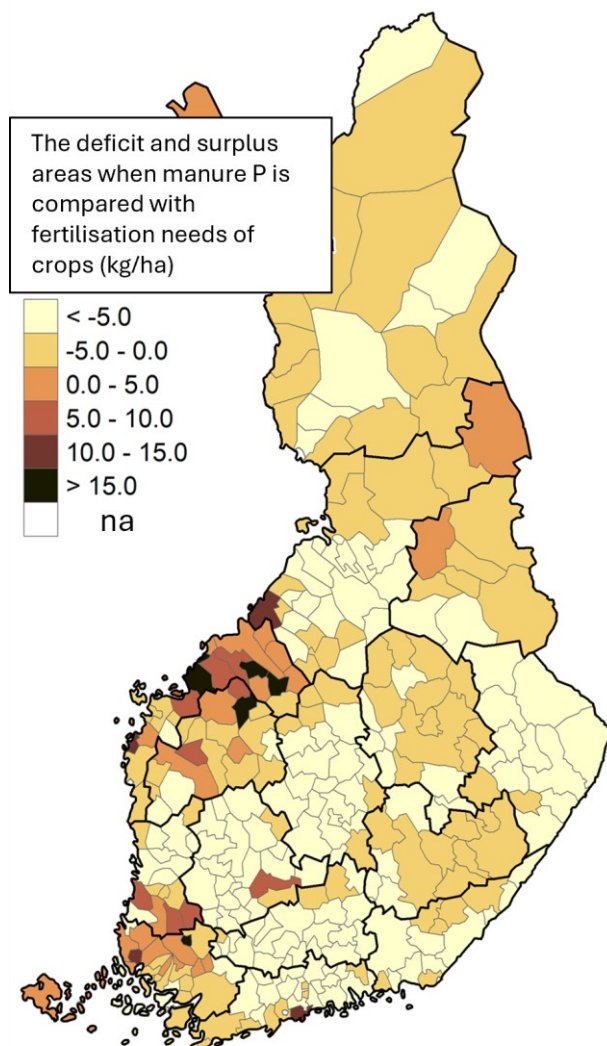


Figure 46. The sufficiency of phosphorus in manure for fertilisation, according to the crop need (kg/ha). Surpluses and deficits are presented at a municipal level. Figure adapted from Lemola et al. (2023).

In all recyclable biomasses, including manure, sewage sludge, municipal biowaste and food industry wastes and side streams, an estimated 4.4 million kg of phosphorus remains unused for fertilization purposes (Figure 47). The largest proportion of unused phosphorus in agriculture is found in sewage sludge, a lot of which is used in landscaping. If the total phosphorus content of all the biomasses considered in this review could be processed into fertilizing products and used in agriculture, it covers 90% of the phosphorus required for plant production in the 2023 estimation.

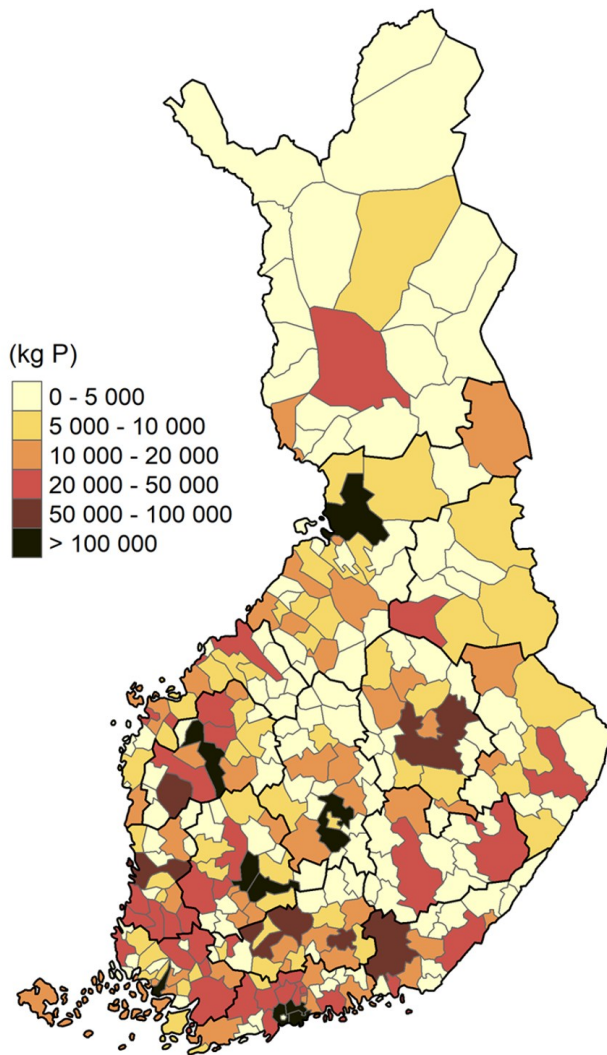


Figure 47. Potential phosphorus in biomasses that is not used for fertilization, by municipality level (kg). The estimated total of unused phosphorus for fertilization purposes is 4.4 million kg. Figure adapted from Lemola et al. (2023).

References

- Lemola, R., Uusitalo, R., Luostarinen, S., Tampio, E., Laakso, J., Lehtonen, E., Skyttä, A. & Turtola, E. 2023. Fosforin kierrätyksen tarve ja potentiaali kasvintuotannossa : Synteesiraportti. Luonnonvara- ja biotalouden tutkimus 10/2023. Luonnonvarakeskus. Helsinki. 56 s. <https://urn.fi/URN:ISBN:978-952-380-612-2>
- Valkama, E., Uusitalo, R. & Turtola, E. 2011. Yield response models to phosphorus application: a research synthesis of Finnish field trials to optimize fertilizer P use of cereals. *Nutrient Cycling in Agroecosystems* 91: 1–15. <https://doi.org/10.1007/s10705-011-9434-4>
- Valkama, E., Virkajärvi, P., Uusitalo, R., Ylivainio, K. & Turtola, E. 2015. Meta-analysis of grass ley response to phosphorus fertilization in Finland. *Grass and Forage Science* 71(1): 36–53. <https://doi.org/10.1111/gfs.12156>
- Ylivainio, K., Sarvi, M., Lemola, R., Uusitalo, R. & Turtola, E. 2014. Regional P stocks in soil and in animal manure as compared to P requirement of plants in Finland. MTT Report 124, 35 s. <https://urn.fi/URN:ISBN:978-952-326-129-7>

5. Conclusions

Nutrient recycling means the measures to reuse the nutrients already being exploited in the societies and ending up in wastes and side streams. The measures can be simple with direct new use of the nutrient-rich biomasses or complex to various degrees with processing of the biomasses to new products. While nutrient recycling is done already, it can often be significantly enhanced by implementation of different actions. To plan and promote these actions, information on the potential recyclable biomasses, including their amounts, spatial distribution and current uses need to be known. As the main reuse for nutrients is agricultural production, the nutrient recycling potential should also be tied to the fertilization need.

The data required to estimate the amount of nutrients in recyclable biomasses per country or region is usually scattered into different sources with gaps in the chain from the place of origin to end-use. In this report, recyclable biomasses were mapped with two different methods for the Baltic Sea Region.

While the Eurostat-based method is uniform for all countries, it is limited. The best spatial resolution available, NUTS2 level, offers rather coarse data still for most of the Baltic Sea countries and fails to highlight the regional distribution within the countries. Moreover, Eurostat mostly offers amounts of different wastes and the number of animals in certain categories but does not contain information on their nutrient contents. Thus, general nutrient coefficients need to be used, failing to consider national differences in the characteristics of different recyclable biomasses.

Using nationally available statistics and other data sources may provide nationally more relevant information in a more detailed spatial resolution. However, the data are usually scattered and piecing it together is laborious. There are also data gaps and uncertainties. Due to this variation in the data availability, it is difficult to develop a method suitable for all countries.

The results of this report give indication of the nutrient recycling potential in the Baltic Sea Region and can be used as a starting point to improve data collection and monitoring of the potential regularly on national and transnational scale. The monitoring process should be organized in the Baltic Sea countries in a controlled way by designating the responsible organization(s), resourcing it/them sufficiently to enable a regular updating process and supporting them with improving the data collection on the biomasses across sectoral boundaries and different needs for nutrient-related information (e.g. emission inventories, nutrient balances, environmental permitting and supervision of production and use of fertilizing products).

The monitoring should also contain comparison of the nutrient recycling potential and the fertilization need in each country and region. The simplest way is to compare the amount of recyclable nutrients to the area of utilized agricultural land in each region, as presented in this report, but this fails to properly consider the fertilization need. An example of more detailed analysis considering the fertilization need is given here for Finland. The comparison identifies regions of surplus and deficiency for nutrient recycling, as in some regions there is significantly more recyclable nutrients available than is needed in the agricultural production, while others could receive recycled fertilizing products to reduce the need for mineral fertilizers. As the recyclable nutrients are often rather diluted in large volumes to be transported,

information on surplus and deficit regions gives direct indication to where the biomasses should be processed to concentrate them for reallocation and enhanced nutrient use.

Thus, the information on nutrient recycling potential and fertilization need pave the way for targeting nutrient recycling measures within countries and regions and serves as the basis for planning activities for enhanced nutrient use. To improve the situation, the current practices also need to be known. As part of the monitoring process of nutrient recycling, the current situation also needs to be followed as described in another CiNURGi report ([Luostarinen \(ed.\) 2025](#)).

The methodology for monitoring nutrient recycling should still be developed further. While the scientific community needs to be involved, also support from other stakeholders is needed. Policy makers need the nutrient recycling data for promoting it, and they should also promote improved data collection over sectoral barriers together with different authorities. Many data required can be found in regulatory contexts, e.g. in national statistics, reporting for environmental permitting, supervision of quality and production of fertilizing products, and used in nationally binding emission inventories and other reporting. There are still data gaps which can be closed if the different data collections are developed as a whole. Also, the stakeholders producing, processing and using recycled nutrients should be informed of the data needs and given reasons to motivate them to fill in the reports and surveys properly. The better the data quality, the better the measures to promote nutrient recycling can be. The scientific community should build such instructions that give a proper framework for monitoring nutrient recycling but are also flexible enough to ensure consideration of national differences in the recyclable biomasses, their properties and data availability.

Appendix: Description of the Eurostat-based method

Livestock manure

Geographical data

The Baltic Sea shares coastline with Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Russia, Poland and Germany. The catchment area of the Baltic Sea spans also to regions of Slovakia, Czech Republic, Ukraine, Belorussia and Norway (Figure 1, HELCOM 2021²). The Baltic Sea region countries included in this report are Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Finland and Sweden.

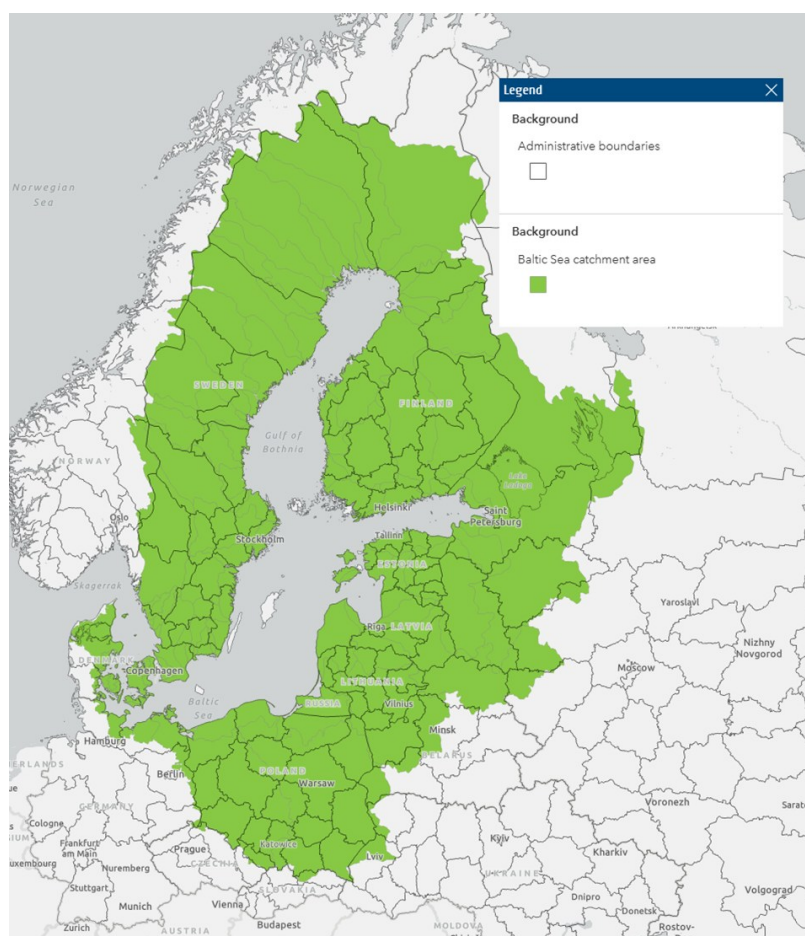


Figure 1. The Baltic Sea catchment area and administrative boundaries of the coastal countries. Map is from HELCOM Map and data service, accessed 7.11.2025.

In Eurostat, region means a sub-division of a Member State territory. For livestock and poultry statistics, 'region' refers to NUTS 2, except for Germany, for which the numbers of

² HELCOM 2021. Background information on the Baltic Sea catchment area for the Seventh Baltic Sea Pollution load compilation (PLC-7). [Background-information-on-the-Baltic-Sea-catchment-area-for-the-Seventh-Baltic-Sea-Pollution-load-compilation-PLC-7-211202.pdf](#)

livestock and poultry are given by NUTS1. It is necessary to check whether there has been changes in regions between 2020 and 2023, as Eurostat data for the livestock is available in 2023 and for the poultry in 2020 and data from both years must be summed up to regions⁴.

The NUTS1 regions for Germany and NUTS2 regions for other countries are listed in Table 1. The regulation requires that the classification remains unchanged for a minimum of three years. Maintaining stability means the data consistently corresponds to the same regional area over time. This is especially important for producing reliable statistics, such as time series analyses. However, year 2020 belongs to period 2016-2020 and 2023 belongs to period 2021-2024. Fortunately, there were no region changes in the Baltic Sea countries between periods.

Extra-Regio territories referring to parts of a country's economic territory that cannot be directly assigned to a specific NUTS region were excluded from analysis. These areas, like air-space, territorial waters, embassies, and resources in international waters, are included in the NUTS classification, but not counted when determining the number of regions at a particular NUTS level.

Thus, in total eight countries and 77 regions were included in manure calculations (Table 1).

Table 1. NUTS1 regions.

Country, NUTS-level used, number of regions	Region code	Region name
Germany, NUTS1, 15	DE2	Bayern
	DE3	Berlin
	DE4	Brandenburg
	DE5	Bremen
	DE6	Hamburg
	DE7	Hessen
	DE8	Mecklenburg-Vorpommern
	DE9	Niedersachsen
	DEA	Nordrhein-Westfalen
	DEB	Rheinland-Pfalz
	DEC	Saarland
	DED	Sachsen
	DEE	Sachsen-Anhalt
	DEF	Schleswig-Holstein
DEG	Thüringen	
Denmark, NUTS2, 5	DK01	Hovedstaden
	DK02	Sjælland
	DK03	Syddanmark
	DK04	Midtjylland
	DK05	Nordjylland
Estonia, NUTS2, 1	EE00	Eesti
Finland, NUTS2, 5	FI19	Länsi-Suomi
	FI1B	Helsinki-Uusimaa
	FI1C	Etelä-Suomi
	FI1D	Pohjois- ja Itä-Suomi
	FI20	Åland
Lithuania, NUTS2, 2	LT01	Sostinės regionas
	LT02	Vidurio ir vakarų Lietuvos regionas
Latvia, NUTS2, 1	LV00	Latvija
Poland, NUTS2, 17	PL21	Małopolskie
	PL22	Śląskie
	PL41	Wielkopolskie
	PL42	Zachodniopomorskie
	PL43	Lubuskie
	PL51	Dolnośląskie
	PL52	Opolskie
	PL61	Kujawsko-pomorskie
	PL62	Warmińsko-mazurskie
	PL63	Pomorskie
	PL71	Łódzkie
	PL72	Świętokrzyskie
	PL81	Lubelskie
	PL82	Podkarpackie
	PL84	Podlaskie
	PL92	Warszawski stołeczny
PL92	Mazowiecki regionalny	
Sweden, NUTS2, 8	SE11	Stockholm
	SE12	Östra Mellansverige
	SE21	Småland med öarna
	SE22	Sydsverige
	SE23	Västsverige
	SE31	Norra Mellansverige
	SE32	Mellersta Norrland
	SE33	Övre Norrland

Livestock populations

The calculation of the nutrient content of livestock manure is based on the number of animals in the Baltic Sea countries, as reported to Eurostat. However, as the amount of manure is dependent on the shares of different manure types produced by each relevant animal category in each country. Because such data is not readily available (though some estimates for some animal categories and some manure types can be found from the literature), it was decided that the amount of manure is not estimated here. Only the nutrient content is estimated using excretion coefficients, i.e. how much nitrogen and phosphorus is excreted by the animals.

Livestock populations for ruminants and pigs by NUTS 2 region are found in Eurostat statistics > Regional Agriculture Statistics (agr_r) > agr_r_animal. The number of animals (expressed in units of 1 000 head) refers to the situation in December of the year of statistics. Year 2023 was the latest data available at time of the analysis. Livestock population is accounted by categories that capture their rearing, either for fattening then slaughter, or for herd renewal, i.e. for breeding and/or milking^{3,4}.

Number of poultry is taken from Eurostat Poultry types by utilized agricultural area, size classes of livestock and NUTS 2 region [ef_lsk_poultry]⁵. The latest data for poultry was available for the year 2020. Eurostat provides poultry data in three different units: Heads (HD), Livestock units (LSU), and Holding (HLD). Here, heads were used as it indicates the actual number of animals, whereas livestock units allow comparisons across species and holdings showing how many farms are rearing poultry. Poultry is available in NUTS2 regions for all BSR countries, but the German poultry data was summarized from NUTS2 to NUTS1 to unify with the number of livestock⁶.

Animal categories included to the calculation for manure nutrients are in Figure 2 for bovine, Figure 3 for pigs and Figure 4 for poultry⁷. All included animal categories are presented in Table 2 together with excretion coefficients used for nutrient calculation. It is notable, that Eurostat provides data for many other animal categories for some countries, and they are not included in calculations because of overlapping categories.

³ Eurostat 2024. Statistics Explained. Agriculture statistics at regional level. Data extracted in March 2024. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agriculture_statistics_at_regional_level#Livestock_and_milk

⁴ Eurostat 2025a. Reference Metadata for Animal production [Animal production \(apro_anip\)](#)

⁵ https://doi.org/10.2908/EF_LSK_POULTRY

⁶ Eurostat Farm Structure. 2024. Reference metadata. [Farm structure \(ef\)](#)

⁷ Eurostat Integrated Farm Statistics Manual. 2023 edition. 3. Classification - Variables of livestock <https://wikis.ec.europa.eu/spaces/IFS/pages/83690017/3.1+IFS+Core#id-3.1IFSCore-Variablesoflivestock>

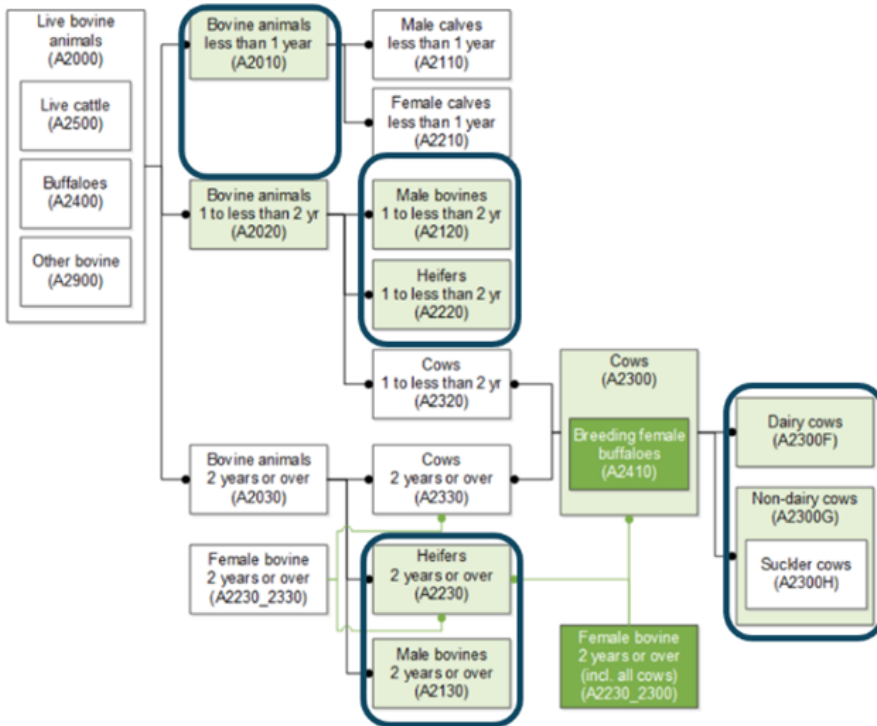


Figure 2. Bovine classification in agr_r_animal. Bovine animals included in manure nutrient calculation are indicated with dark blue rectangles. Figure from [3.1 IFS Core - IFS-Integrated-Farm-Statistics - EC Public Wiki](#).

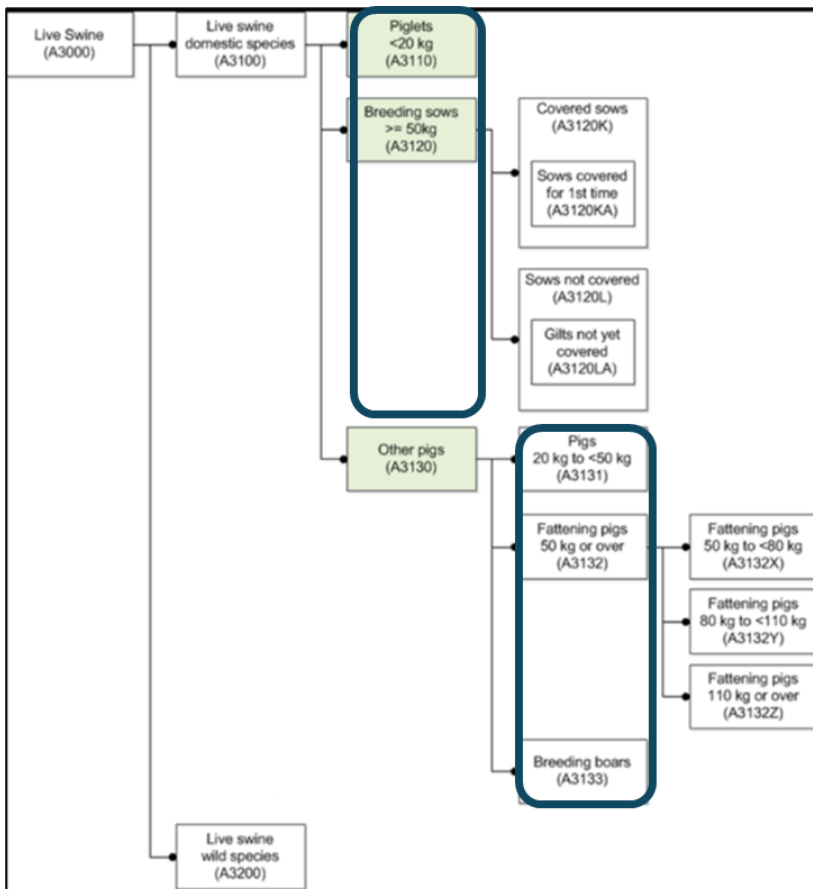


Figure 3. Pig classification in Eurostat agr_r_animal. Pigs included in manure nutrient calculation are indicated with dark blue rectangles.

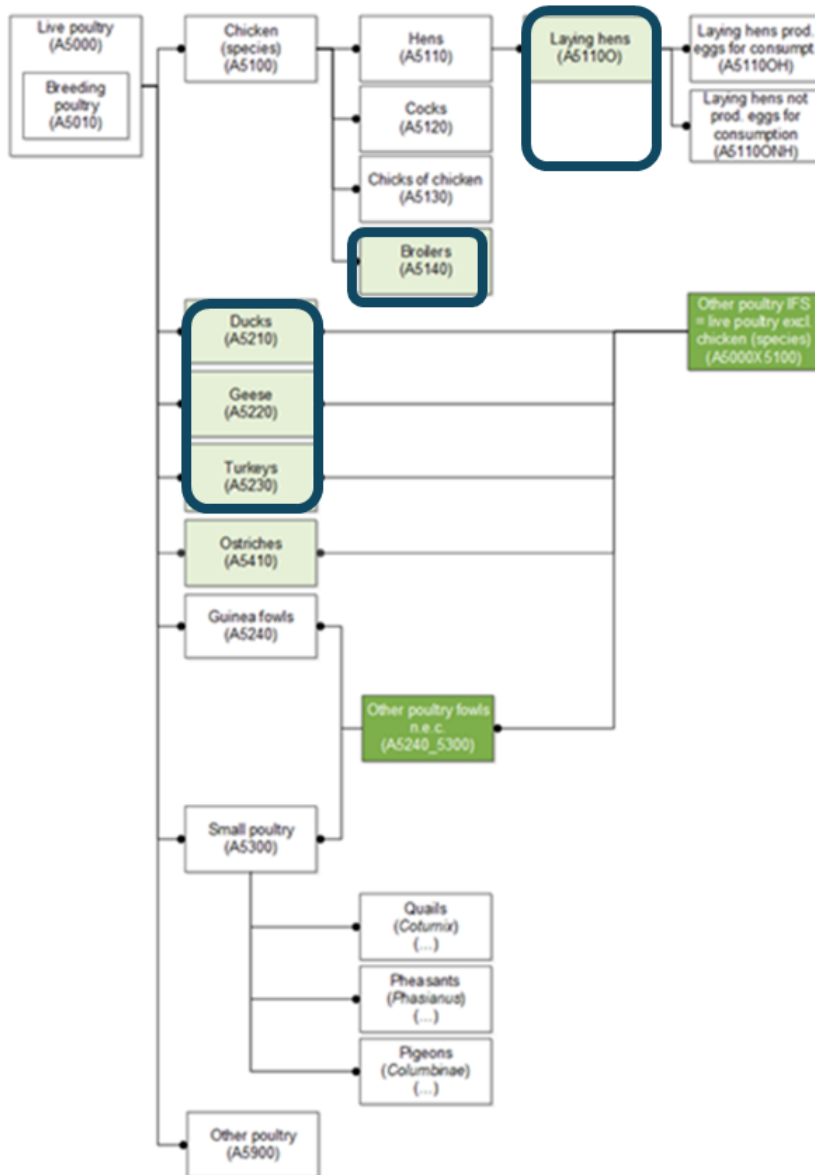


Figure 4. Poultry classification in Eurostat ef_Isk_poultry⁸. Poultry included in manure nutrient calculation are indicated with dark blue rectangles.

The amount of nitrogen and phosphorus in livestock manure was then a multiplication with the number of animals and respective excretion coefficients. The excretion coefficients used here are based on the German legislation Düv 2017⁹ (Table 2).

⁸ Eurostat statistics explained. Glossary: Poultry. ISSN 2443-8219 [Glossary:Poultry - Statistics Explained - Eurostat](#)

⁹ Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen 2 (Düngeverordnung - DüV). https://www.gesetze-im-internet.de/d_v_2017/anlage_1.html

Table 2. Animal classification in Eurostat and the respective nitrogen and phosphorus excretion coefficients (adopted from Duv 2017).

Eurostat code for animals	Animal label	N (kg/head/year)	P (kg/head/year)
A2010	Bovine animals, less than 1 year old	15.2	2.63
A2120	Male bovines 1 to less than 2 years	38.8	6.29
A2220	Heifers, 1 to less than 2 years old	38.8	6.29
A2130	Male bovine animals, 2 years old or over	41.3	6.46
A2230	Heifers, 2 years old or over	51	6.87
A2300F	Dairy cows	130	19.8
A2300G	Non dairy cows	102	13.1
A3110	Piglets, live weight of under 20 kg	3.7	0.6
A3120	Breeding sows, live weight 50 kg or over	24.8	4.96
A3131	Pigs, from 20 kg to less than 50 kg	9.9	2.2
A3132	Fattening pigs, live weight 50 kg or over	11.1	1.89
A3133	Breeding boars	22.1	4.19
A4100	Live sheep	19.3	1.89
A4200	Live goats	15.2	2.49
A5110O	Laying hens	0.7	0.16
A5140	Broilers	0.3	0.07
A5210	Ducks	0.6	0.16
A5220	Geese	0.7	0.17
A5230	Turkeys	1.7	0.38

Utilized agricultural area

Utilized agricultural area was taken from Eurostat "Farms and hectares by crops, utilized agricultural area, economic size of the farm and NUTS 2 region" [ef_lus_allcrops]. The latest available data was on 1st Jan 2020. Units are ha of total utilized agricultural area. Data for Germany was summarized from NUTS 1 to NUTS2 to combine it with manure nutrient data¹⁰.

Sewage sludge

Sewage sludge data was similarly prepared as in Luostarinen et al. 2021¹¹ by utilizing Eurostat Data Browser and dataset "Sewage sludge production and disposal [env_ww_spd]" (updated 05/07/2024). In the dataset, the following dimensions were selected:

- Wastewater treatment plant parameters: Sludge production - total
- Wastewater treatment plants: Urban wastewater treatment plants - total
- Unit of measure: Thousand tonnes (represents dry weight)

¹⁰ Eurostat 2025. Farms and hectares by type of crops, utilized agricultural area, economic size and NUTS2 region. https://doi.org/10.2908/EF_LUS_ALLCROPS

¹¹ Luostarinen, S., Lehtonen, E., Skyttä, A., Seppänen, A-M., Tampio E., 2021. Dataset of regional NRSS available for producing BBFs in the EU. Deliverable 1.1 - D5 – WP1. LEX4BIO. https://lex4bio.eu/wp-content/uploads/2022/09/LEX4BIO_D1.1_WP1-1.pdf

Annual sludge production from several years was downloaded. Data from the year of last data inputs was used, which was year 2022 for Estonia, Latvia, Lithuania, Poland and Sweden. Year 2021 was used for Germany and Finland, and year 2010 data for Denmark.

The per capita sludge production was calculated using the sludge production and population data. Population data from year 2023 was derived from Eurostat dataset "Population on 1 January by age, sex and NUTS 2 region [demo_r_d2jan] (updated: 22/07/2024). With country level per capita sludge production and population data, sludge amounts calculated to NUTS2 regions.

The average nutrient content of the sludge (3.85% DM for N and 2.5 %DM for P) was derived from EC (2010)¹², where EU-wide sludge quality parameters were reported.

Municipal biowaste

Municipal biowaste data was also derived as in Luostarinen et al. 2021 utilising EU countries' waste generation reported per capita by Favoino & Gavini (2020)¹³. The 'Current biowaste capture' was used, which refers to the source-separated fraction of organic municipal solid waste. It was further calculated to country and NUTS2-level biowaste production with the population data from year 2023 from the Eurostat dataset "Population on 1 January by age, sex and NUTS 2 region [demo_r_d2jan] (updated: 22/07/2024)

The nutrient content of municipal biowaste was calculated based on the average composition; nitrogen content 7.4 g/kg fresh matter and phosphorus concentration 4 g/kg DM (average DM content 24%) (Banks et al. 2018¹⁴).

In Eurostat, the statistical data regarding source-separated biowaste is not available. Eurostat provides dataset 'Food waste and food waste prevention by NACE Rev. 2 activity - tonnes of fresh mass' [env_wasfw], which food waste generation data from different phases (primary production, manufacture of food products and beverages, retail and other distribution of food, restaurant and food services as well as total activities by households). The data is available from year 2020 onwards. However, this dataset does not provide data on the collected source-separated waste amounts.

The previously available Eurostat dataset on biowaste recycling [cei_wm030] has been discontinued since 16/08/2023.

¹² EC 2010. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part III: Project Interim Reports. https://ec.europa.eu/environment/archives/waste/sludge/pdf/part_iii_report.pdf

¹³ Favoino, E., Giavini, M. 2020. Bio-waste generation in the EU: Current capture levels and future potential-Bio-based Industries Consortium (BIC). 50 pp. https://zerowasteurope.eu/wpcontent/uploads/2020/07/2020_07_06_bic_zwe_report_bio_waste_en.pdf

¹⁴ Banks, C.J., Heaven, S., Zhang, Y., Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018:12. https://www.ieabioenergy.com/wp-content/uploads/2018/12/Food-waste_WEB_END.pdf

Industrial side streams

Industrial side streams are a vast category consisting of variety of different industrial side streams. From the Eurostat Data Browser, data regarding animal by-products, i.e. slaughtering animals, as well as wine industry side streams are available. Both were assessed based on the methodology presented in Luostarinen et al. 2021.

In addition, Eurostat provides data for 'Vegetal waste' and 'Animal and mixed food waste' [env_wasgen] but there is not available data for all member states. For example, for Finland there is no data regarding these waste types. Also, it is not known what types of biomasses are included in these categories, which makes the setting of a nutrient coefficient difficult.

Animal by-products

Animal by-products generation was calculated from the slaughtered animal amounts using the Eurostat Data Browser dataset "Slaughtering in slaughterhouses - annual data [apro_mt_pann]" (updated 19/07/2024). Year 2023 with the latest data inputs was set as the base year. Additionally, in the dataset, the following dimensions were selected:

- Item of meat: Slaughterings
- Unit of measure: Thousand heads (animals)

The dataset was used as the basis of annual amount of national slaughter waste from cattle, pigs, and poultry. No NUTS2-level data was available.

The amount of animal by-products was derived from the amount of slaughtered animals and the average amount of slaughtering waste per animal head. The amount of slaughtering waste for cattle (180 kg/animal), pigs (26 kg/animal) and poultry (0.77 kg/animal) was derived from Finnish Environment Institute (2000)¹⁵, where all the different slaughtering side fractions were taken in account except the hides of cattle.

Furthermore, the nutrient content the slaughtering wastes was calculated based on the average nitrogen and phosphorus concentrations derived from FAO (2018)¹⁶, where the fresh matter based nutrient concentrations were 2.9%N and 0.7%P for cattle, 2.5%N and 0.56%P for pig, and 2.5%N and 0.58%P for poultry slaughter waste.

¹⁵ Finnish Environment Institute 2000. Finnish Expert Report on Best Available Techniques in Slaughterhouses and Installations for the disposal or recycling of animal carcasses and animal waste. The Finnish Environment 539. 42 pp. <http://hdl.handle.net/10138/40549>

¹⁶ FAO. 2018. Nutrient flows and associated environmental impacts in livestock supply chains: Guidelines for assessment (Version 1). Livestock Environmental Assessment and Performance (LEAP) Partnership. Rome, FAO. 196 pp. <https://www.fao.org/publications/card/en/c/CA1328EN/>

Grape pomace

The generation of grape pomace was derived from the grape yield data which was sourced Eurostat Data Browser using dataset "Grapes by production [tag00121]" (updated 30/08/2024) with year 2023 as the base year and selecting the following dimensions:

- Crops: Grapes for wines
- Structure of production: Harvested production in EU standard humidity (1000 t)

In the Baltic Sea Region, grape pomace is a relevant side stream only in Germany.

The grape pomace amounts were further calculated from the grape yield with a factor of 0.13 (Oliveira & Duarte 2016¹⁷).

The nitrogen (1.73 %) and phosphorus concentrations (0.28% DM, DM 24%) were derived from a study by Ferrer et al. (2001)¹⁸.

¹⁷ Oliveira, M., Duarte, E. 2016. Integrated approach to winery waste: waste generation and data consolidation. *Frontiers of Environmental Science & Engineering* 10, 168-176. <https://doi.org/10.1007/s11783-014-0693-6>

¹⁸ Ferrer, J., Páez, G., Mármol, Z., Ramones, E., Chandler, C., Marín, M., Ferrer, A. 2001. Agronomic use of biotechnologically processed grape wastes. *Bioresource Technology* 76, 39-44. [https://doi.org/10.1016/S0960-8524\(00\)00076-6](https://doi.org/10.1016/S0960-8524(00)00076-6)



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