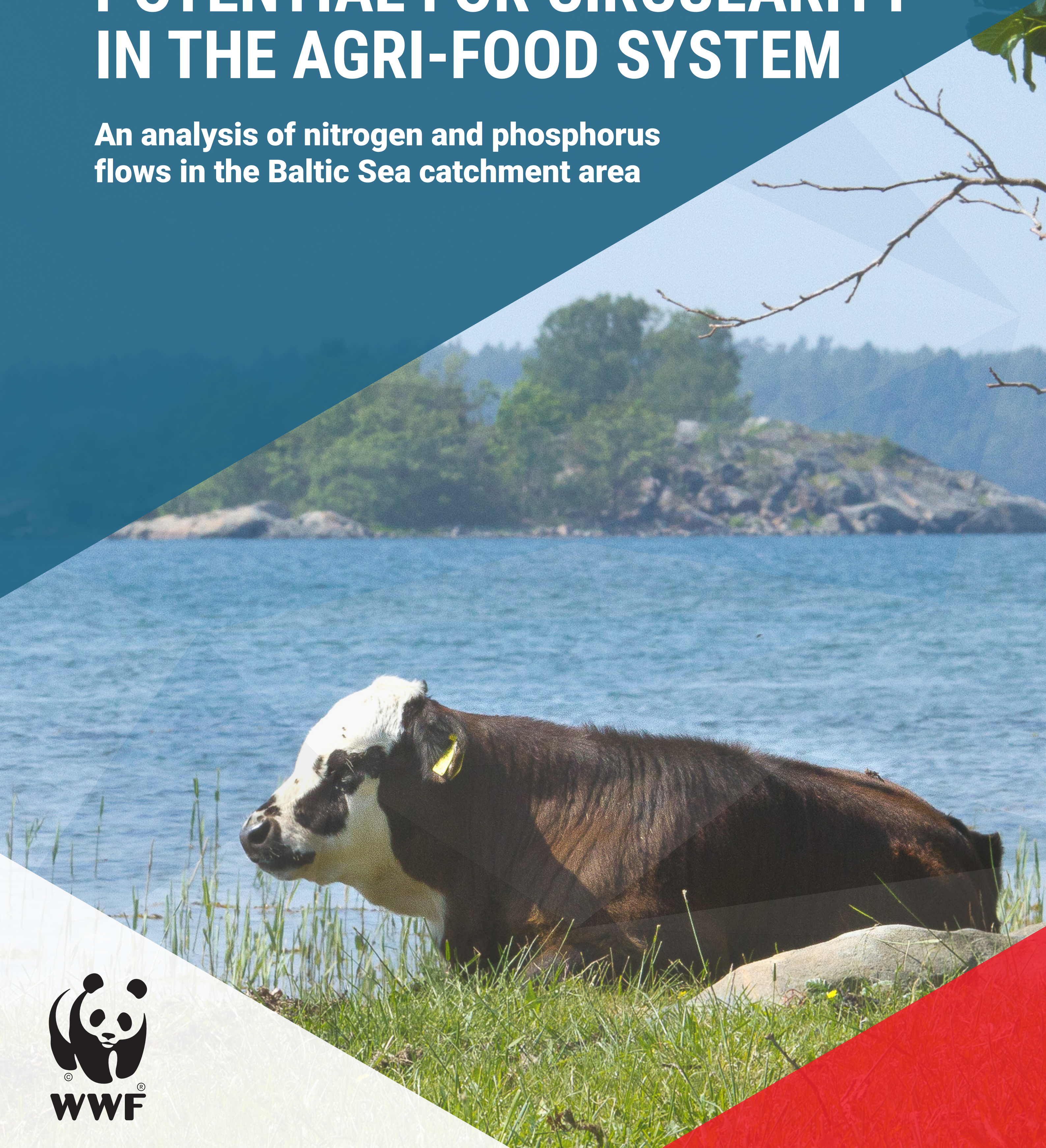
METABOLIC

POTENTIAL FOR CIRCULARITY IN THE AGRI-FOOD SYSTEM

An analysis of nitrogen and phosphorus flows in the Baltic Sea catchment area



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FOREWORD

Eutrophication in the Baltic Sea is a serious and longstanding environmental issue. Together with stakeholders, WWF has worked for decades to improve the status of the sea. Even though changes for the better can be seen in some coastal areas, the situation is still dire with dead zones across the seabed twice the size of Denmark and algal blooms that come earlier every year. Many farmers, farmer organizations and food businesses have worked hard to develop and implement methods to reduce the loads of excess nutrients that end up in the Baltic Sea. Despite these efforts, there is still a great need to reduce nutrient runoff from arable land and take further steps to recycle human waste, crop residues and manure to as large an extent as possible.
Encouragingly, there is an increase in awareness and understanding from all sectors and a stronger will than ever before to act on reducing nutrient loss. New innovations and technologies are emerging in many areas: extraction of phosphorus from sewage sludge and manure, biogas plant technologies, and precision farming to name a few. However, to really push for change, there is a need for new economic incentives to improve market conditions, policy reforms and regulatory frameworks along with successful business models.

In 2020, WWF is launching an initiative called the Baltic Stewardship collaboration for a healthy Baltic Sea. The goal is to establish an engaged cluster of companies and organisations acting for increased competitiveness for the agriculture sector, while minimizing nutrient leakage and closing the nutrient loops. The initiative will tackle the problem of eutrophication by looking at the whole food system and will involve all stakeholders along the food chain.

As a starting point the initiative needed a comprehensive overview of the current state of flow of nutrients within the Baltic Sea catchment area. WWF therefore commissioned Metabolic to analyze the flows of nitrogen and phosphorus within the agri-food system in the Baltic Sea drainage basin. Using a systems analysis and circular economy approach, the report highlights the low level of nutrients that are actually recycled within the region and points out potential hotspots for action.

The results of this report provide an important knowledge base for the Baltic Stewardship project in the upcoming work to develop goals, targets and a roadmap on best practices to adopt to achieve Good Ecological Status (GES) of the sea. The findings from the nutrient flow analysis were discussed with stakeholders in Sweden during a workshop in December 2019. A shared vision was co-created and propositions for concrete activities were put forward. A summary of their output is included in the report. While giving us the overall picture of nutrient cycling in the Baltic Sea, every country around the sea has to move forward and implement solutions that take local context into consideration. It is our hope that reading this report will inspire further collaboration between engaged stakeholders that care for our food system and our Baltic Sea.

EXECUTIVE SUMMARY

PURPOSE

Despite many efforts and some improvements in recent years, the Baltic Sea is in poor health. Almost the entire sea has been affected by an oversupply of nutrients, resulting in eutrophication, ecosystem loss and large dead zones. Agriculture in the Baltic region is the single largest contributor of both nitrogen and phosphorus pollution in the Baltic sea. While both nutrients are critical to food production, excess leakage of them into the soils and waterways of the region causes negative environmental impacts, as well as the loss of a finite resource in the case of phosphorus.

The circular economy may offer a solution to the problem of nutrient oversupply, and to improving nutrient security in the region. A circular economy means cycling materials at their highest value and complexity, which in the case of nutrients in the Baltic, relates to the capture, reuse and recycling of nitrogen and phosphorus. This can reduce the damaging leakage and loss of nutrients to ecosystems, as well as reduce the addition of new nutrients to the region.

To address the potential opportunities for nutrient capture and cycling, we used a Material Flow Analysis (MFA). We analyzed the flows of nitrogen and phosphorus through the food system, including crop and animal production, food consumption and waste treatment. Next, we identified hotspots of nutrient loss, and opportunities for nutrient cycling.

We presented the results of our analysis to a cross-section of stakeholders in the Baltic food system, and collaboratively identified research gaps and potential next steps for increased nutrient cycling in the region.

ANALYSIS OUTCOMES

The outcomes of the analysis show that there are large nutrient losses occurring in the agri-food system. Over half of all nitrogen and phosphorus applied to crops are lost to the hydrosphere. Additionally, there is a considerable in-flow of new nutrients into the system. The two main sources of additional nutrients are mineral fertilizers and manure derived from imported animal feed, which together make up 80% of all nitrogen and 75% of phosphorus applied to crops in the region.

Key opportunities for nutrient capture are in food waste, sewage sludge, animal production waste, and other organic materials such as crop residues and unused manure. Additionally, there is an undersupply of manure in some areas, and an oversupply in others, exacerbating both the inflow of new mineral fertilizers and the loss of nutrients to the hydrosphere.

In total, we calculate that there are 1258 kilotons of nitrogen and 281 kilotons of phosphorus within the system that are currently under-utilised. This represents 61% of the total added mineral nitrogen and 1.21 times the total fossil phosphorus applied to crops for fertilization.

STAKEHOLDER ENGAGEMENT

We hosted a workshop with key stakeholders from the Baltic food system to communicate our results, and to co-develop a vision for a Baltic Food System that cycles nutrients and other materials more effectively. We invited the stakeholders to help us identify research gaps, to think about how the characteristics of the Baltic food system could support circularity, what existing platforms and programs we should build on.

Research gaps

Horsekeeping, pets, and other forms of animal husbandry should be included

Participants in the workshop proposed that there are large flows of nutrients not accounted for, associated with pets, fur-farming and horse-keeping that could provide additional resources for capture and cycling.

A more complete picture of the food system is necessary

Currently not included in our study is food imported from outside the Baltic Sea catchment area, regional trade, as well as certain minor parts of the catchment area that were omitted to align our methodology with existing studies of the region.

Economic and competitive considerations cannot be overlooked

The identification of available resources at the system level is a good starting point in developing more circularity in the region. However, a clearer understanding of the costs and benefits of these strategies, oer a longer time-frame, is crucial. A systemic analysis of benefits and trade-offs around redirecting resources should be carried out to ensure that nutrients and materials are cycled at the highest possible value and material complexity.

Ways Forward for Increased Cycling of Nutrients

Develop standardized nutrient bookkeeping and data infrastructure for the catchment area.

It was recommended that mandatory, standardized nutrient bookkeeping be legislated for the region. This would enable the clear tracking and record keeping of nutrient use and flows, to allow for adaptive decision making to mitigate problematic areas at a more granular scale.

Build on existing collaborations and success stories with farmers

New approaches and activities for reducing nutrient input to the system and for capturing and utilizing nutrient flows can be tested and scaled through existing schemes. More action can be achieved through collaboration, for example through catchment approaches to managing and sharing nutrient budgets.

Mineral fertilizers should be recycled and carbon neutral

To keep us planetary boundaries, mineral fertilizer should, insofar as possible, be produced with recycled nutrients. To reduce the impacts around the production of mineral fertilizers, all non-cycled and cycled forms should be produced in a carbon-neutral manner.

Technology & innovation for nutrient capture must be supported

Innovating for the capture of nutrients from all the streams available, including human and food waste need to be enhanced to close the loop on nutrient cycles. Great examples are already in place, such as capturing of nitrogen from point emissions, and phosphorus from waste-to-energy incineration plants, and the production of animal feed from food waste through insect production. These and other new technologies need assistance to scale up and to be plugged into existing infrastructures around waste treatment.

Civil society should continue to advocate and convene

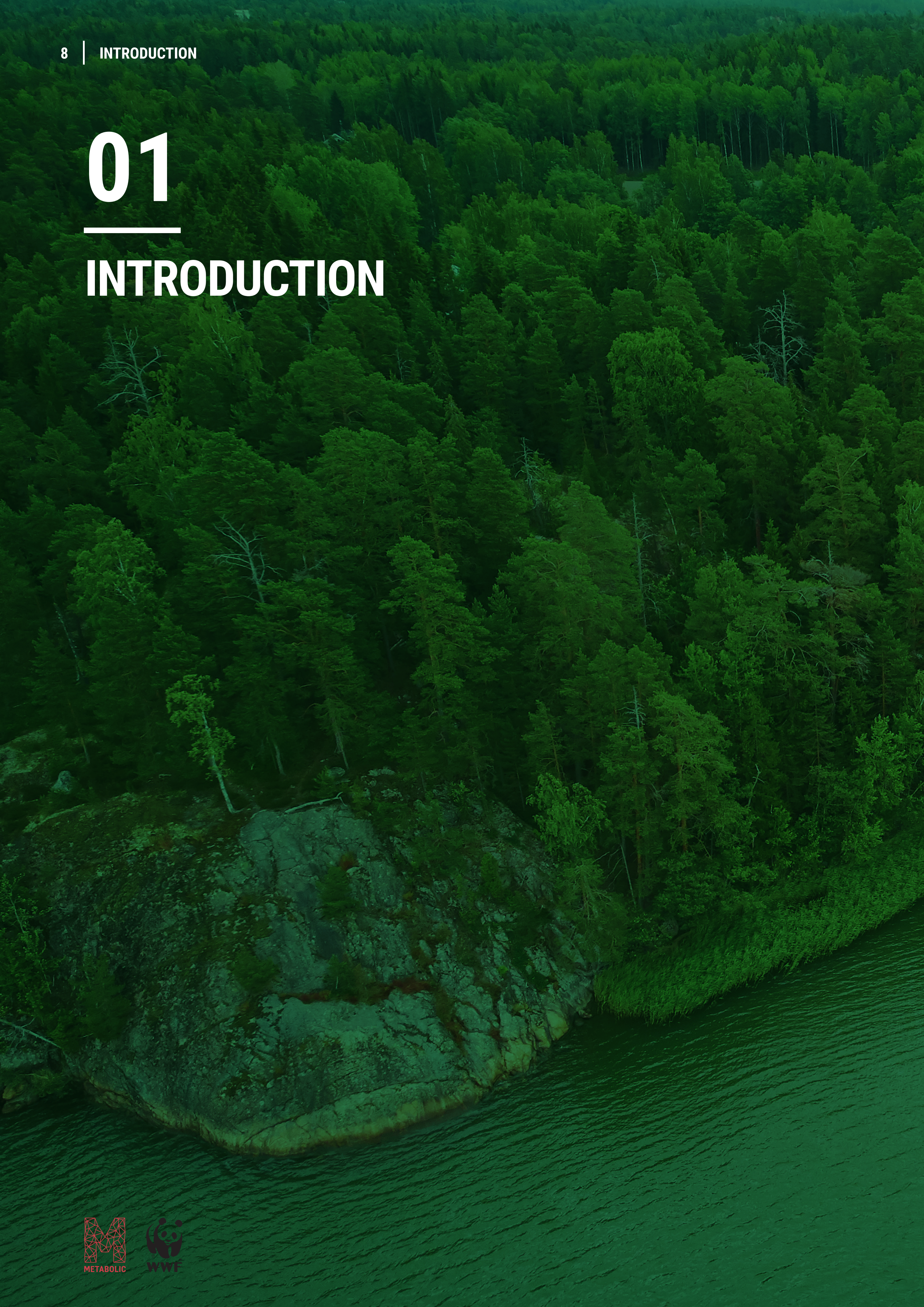
Non-governmental organizations have an important role to play as conveners, in creating knowledge platforms and complementary instruments, and in developing partnerships and collaborations to accelerate the transition into a circular and resource-efficient food system.

Consumers must be made more aware

Building consumer awareness can increase the demand for more nutrient-friendly products. Certification schemes in the region may be one way to incentivize better nutrient management at the production phase of the value chain.

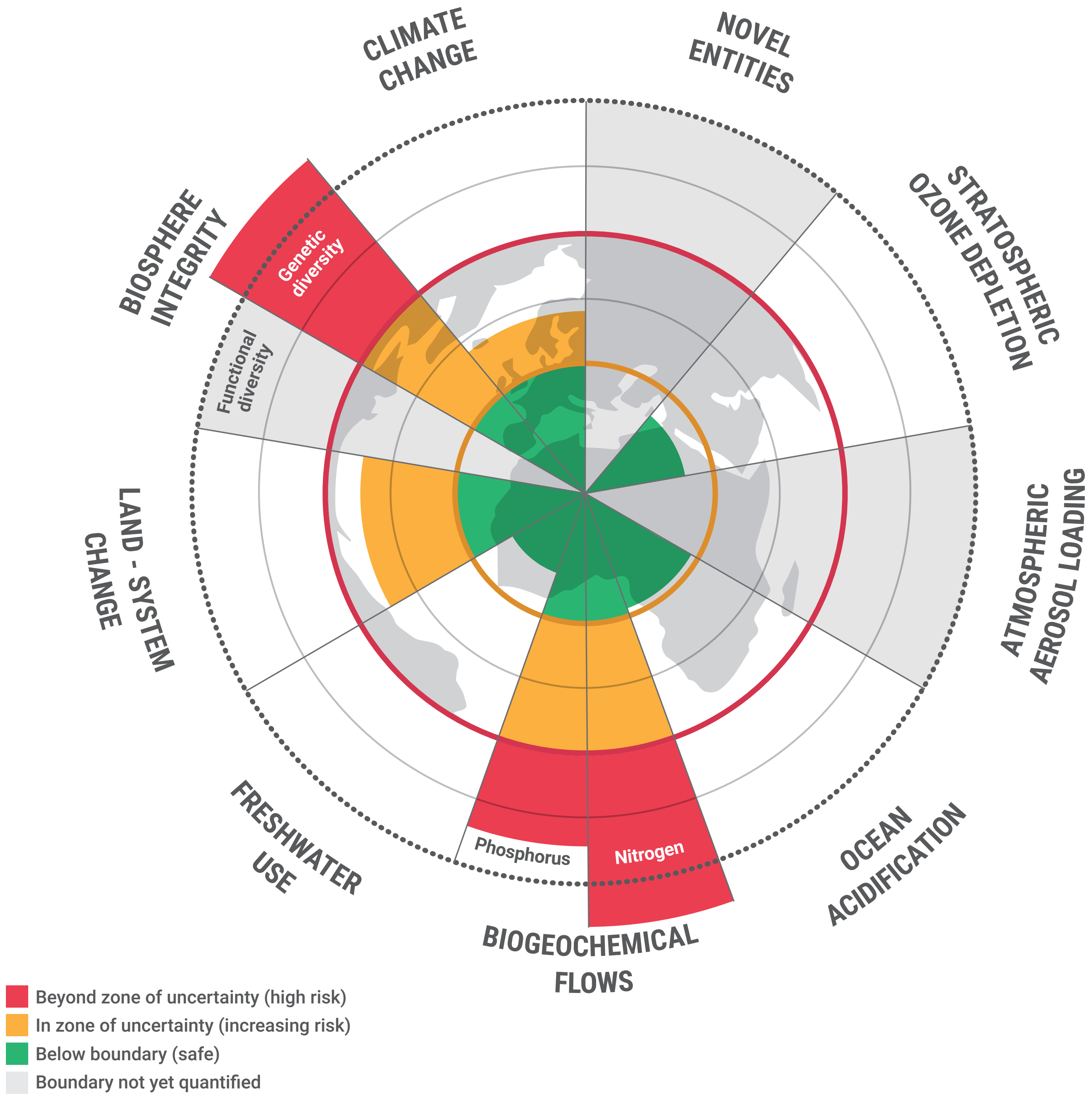
01

INTRODUCTION



The planetary boundaries framework identifies nine interrelated processes which regulate the stability of the Earth system (Rockström et al., 2009). The framework defines a “safe operating space” for each of these processes, outside of which we risk large-scale irreversible changes to the Earth system which would be catastrophic for human development. The most recent estimates suggest that the boundary for biogeochemical flows - nitrogen and phosphorus - has already been exceeded (Steffen et al., 2015).

The impacts of this overshoot are myriad, including large-scale anthropogenic influence on their biogeochemical cycles, resulting in widespread effects on ecosystems. Additionally, while nitrogen is an abundant resource in the form of atmospheric nitrogen, phosphorus is derived from phosphate mineral rock, a finite resource listed as a critical raw material of economic importance with a high supply risk (EC, 2014). Additionally, the conversion of inert atmospheric nitrogen to bioavailable states for fertiliser requires large amounts of energy, often with an associate greenhouse gas impact.



Source: *Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, Science, 16 January 2015.*
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During the 20th century, the Baltic Sea has become a highly eutrophic marine environment, with vast dead zones of little or no oxygen that can no longer support marine life. Most recent studies indicate that about 97% of the Baltic Sea is affected, whereof 12% being highly affected (HELCOM, 2018a). The European Environmental Agency classified 99.4% of the Baltic as a problem area due to nutrient pollution (EEA, 2019a).

Due to being semi-enclosed, the Baltic Sea has a very low refresh rate, meaning it takes approximately 30 years for all of the water to be exchanged with the connected water bodies, making it particularly sensitive to nutrient inputs (Voss et al., 2011). Nitrogen and phosphorus are both critical nutrients for agricultural production, however each present its own challenges and issues. These inputs lead to severe disruption of the aquatic ecosystem through algal blooms, deoxygenated dead zones, and the loss of biodiversity.

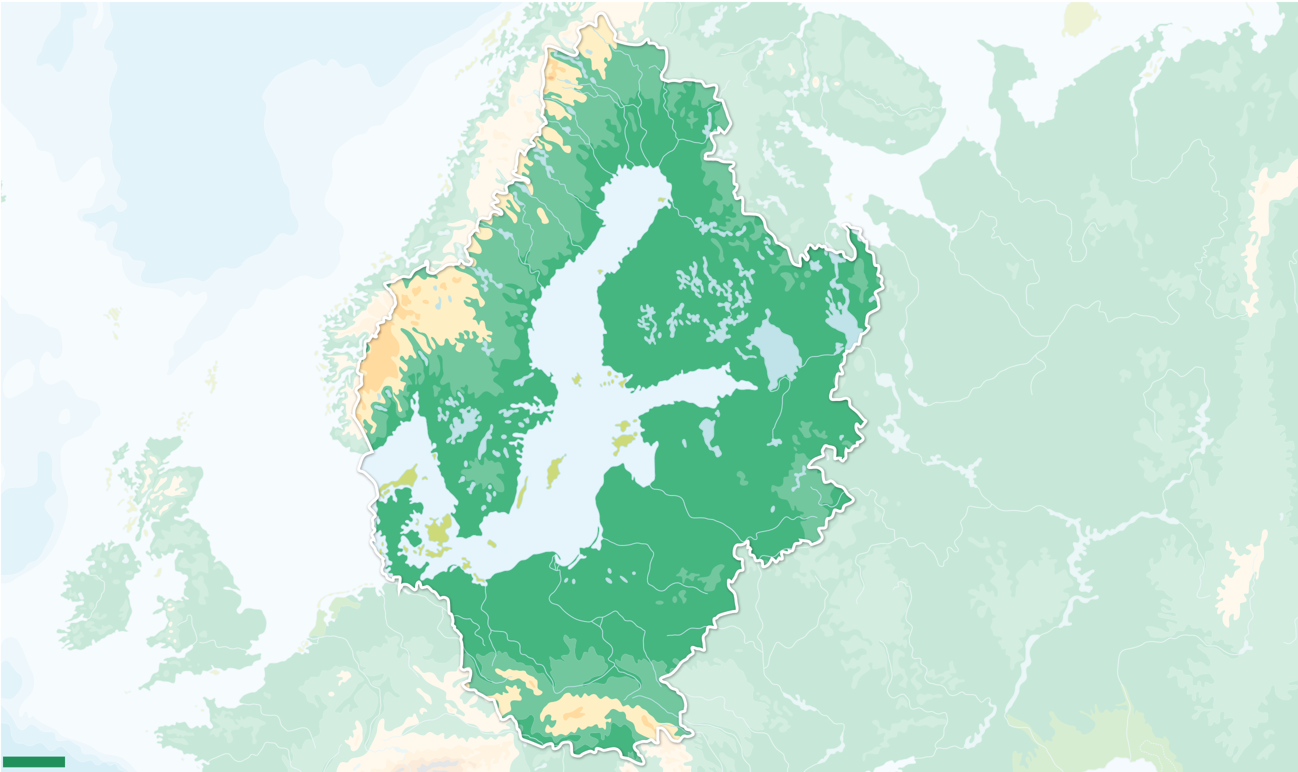
Nutrients enter the Baltic Sea via three major pathways; riverine, airborne and via direct sources such as wastewater treatment plants and industry. While in recent years improvements have been made in the overall ecological state of the Baltic Sea, ongoing issues still exist in certain parts. Significant improvements have been made with industrial and wastewater point emissions, while riverine emissions remain the single largest source of nutrients entering the system (HELCOM, 2018b).

The sources of nitrogen and phosphorus entering rivers can be seen in figures 1 ans 2. While much work has gone into addressing the issue, agricultural runoff remains the single largest contributor to riverine load in the Baltic, , accounting for 46% of nitrogen and 36% of phosphorus together with forestry (HELCOM, 2018b). These losses are a product of the interplay of climate, topography, soils, and agricultural practices, each of which vary considerably throughout the catchment area (Andersen et al., 2016).

The goal of this report is to gain a baseline understanding of nutrient flows in the agri-food system of the Baltic Sea catchment area. We define the agri-food system as all the practices and sectors involved in the production and consumption of food, and the related waste treatment. This baseline will focus on the distribution of nutrients according to crop and animal production type, as well as according to the countries in the Baltic catchment.

We define the agri-food system as all the practices and sectors involved in the production and consumption of food, and the related waste treatment.

Following this analysis, the results were communicated to key stakeholders in a workshop to identify gaps and implications, and to collectively define a vision for the region, and its potential for circularity in the agri-food system.



The Baltic Sea is a body of semi-brackish water bordered by nine countries with an additional five upstream states in its catchment area.

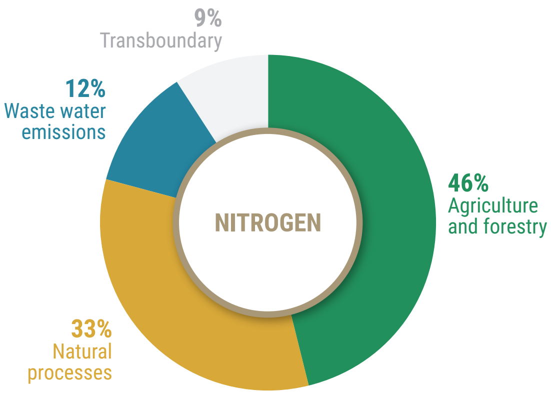


Figure 1: The proportions of sources of nitrogen entering rivers in the Baltic Sea catchment area in 2014 (Riverine load in 2014 to Baltic Sea, HELCOM, 2018b).

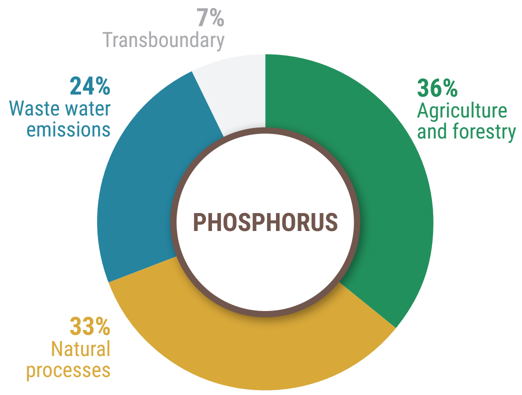


Figure 2: The proportions of sources of phosphorus entering rivers in the Baltic Sea catchment area in 2014 (Riverine load in 2014 to Baltic Sea, HELCOM, 2018b).

02

NUTRIENTS IN THE BALTIC

The main cause of eutrophication in the Baltic Sea varies across the area; in some areas excess nitrogen is the cause and in others, excess phosphorus. Both nutrients behave differently in land and water ecosystems, and they are produced in fundamentally different ways for use as fertilizers. In the two infoboxes below, we discuss the key issues with each in the context of circular agriculture, highlighting that there are many undesirable environmental impacts in their production and use. Additional critical aspects arise for both, phosphorus being a limited and non-renewable resource, and for nitrogen the challenge is the constant inflow of new nitrogen into the Baltic system and the associated ecological impacts.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PLANETARY BOUNDARIES & NITROGEN

The Haber-Bosch process enables unreactive atmospheric nitrogen to be converted to a reactive form. This has been the driver of the green revolution, where agriculture was released from the limitations of natural nitrogen availability and huge gains in food production were achieved.

However, this increase in reactive nitrogen has also led to a range of health, climate and environmental impacts (Galloway et al., 2003; 2008; Erisman et al., 2013). Different plant species require different levels of nutrient availability in soils, as such, the composition of biodiversity in a given place is partially a result of limitations to available nitrogen in the soil. Increasing available nitrogen alters this ecosystem balance, meaning that the continual addition of nitrogen has had long-term impacts on species composition and abundance, (Dise et al., 2011; Stevens et al. 2010). According to Sala and colleagues (2000), the deposition of nitrogen is the third most important driver of terrestrial biodiversity loss.

Nutrient pollution from fertilizer and manure application enter groundwater through leaching, and reach surface water through runoff, while discharge from wastewater treatment plants and sewage systems go directly into surface waters. These pollutants are carried downstream to the sea. The consequences of this are eutrophication and algal blooms leading to biodiversity loss and decreased ecosystem resilience in both freshwaters and seas (Grizzetti et al, 2011).

According to Rockstrom (2009) and Steffen (2015), the planetary boundary for nitrogen, a measure of the amount of reactive nitrogen removed for human use, has been exceeded.

However, according to Häyhä and colleagues (2016), the boundary is problematic in the light of increasing food demand due to a growing population. The levels of nitrogen available in the natural system before synthetic fixation would be insufficient to feed today's global population (de Vries, 2013), highlighted as by 2050 we will need up to twice as much nitrogen fertilizer than the year 2000 levels, to meet the projected food demand of more than 9 billion people. Meeting these demands has been estimated to result in additional biodiversity loss, eutrophication and other health and environmental impacts (Liu et al., 2016). It is clear that it is critical to assess the trade-offs between the creation of reactive nitrogen, the production of food for a growing population, and the negative environmental impacts.

While the planetary boundaries framework offers an important indication of global thresholds and their potential interactions, to address the overshoots and analyze trade-offs, the boundaries must be translated to a level aligned to decision making and reporting frameworks. Nykvist (2013) explores downscaling to national levels based on a per capita allocation of nutrient use, while the Swiss Federal Office of the Environment considers how different allocation scenarios would impact a national boundary. However, when setting national targets for nitrogen, there is the danger of local environmental problems being solved at the expense of countries beyond their borders.

An alternative is the calculation of a bottom-up budget, based on agreed quality objectives, e.g. the critical loads for air pollutants, the limit for nitrates contamination in groundwater and drinking water, and the acceptable nitrogen concentration for the good water quality in surface water bodies. On this basis an integrated budget and associated reduction target can be determined (Erisman et al., 2001; de Vries et al., 2013).

Kahiluoto (2015) assessed the nitrogen boundary for Finland with a bottom-up approach based on mineral fertilizer use in agriculture and forestry, other uses of mineral nitrogen, cultivation-induced biological fixation and fossil energy. They state that to reduce the levels of nutrients entering the system and to stay within the safe operating space for Finland, a transformation of diet, waste, and nutrient recycling within the food system must occur. Springmann (2018) calculated scenarios for staying within planetary boundaries, and found that the only scenario to bring us within the safe operating space included a combination of dietary change, reduction of food waste, increased nutrient cycling and the geographic balancing of fertilizers use.

PHOSPHORUS: PEAKS AND IMPACTS

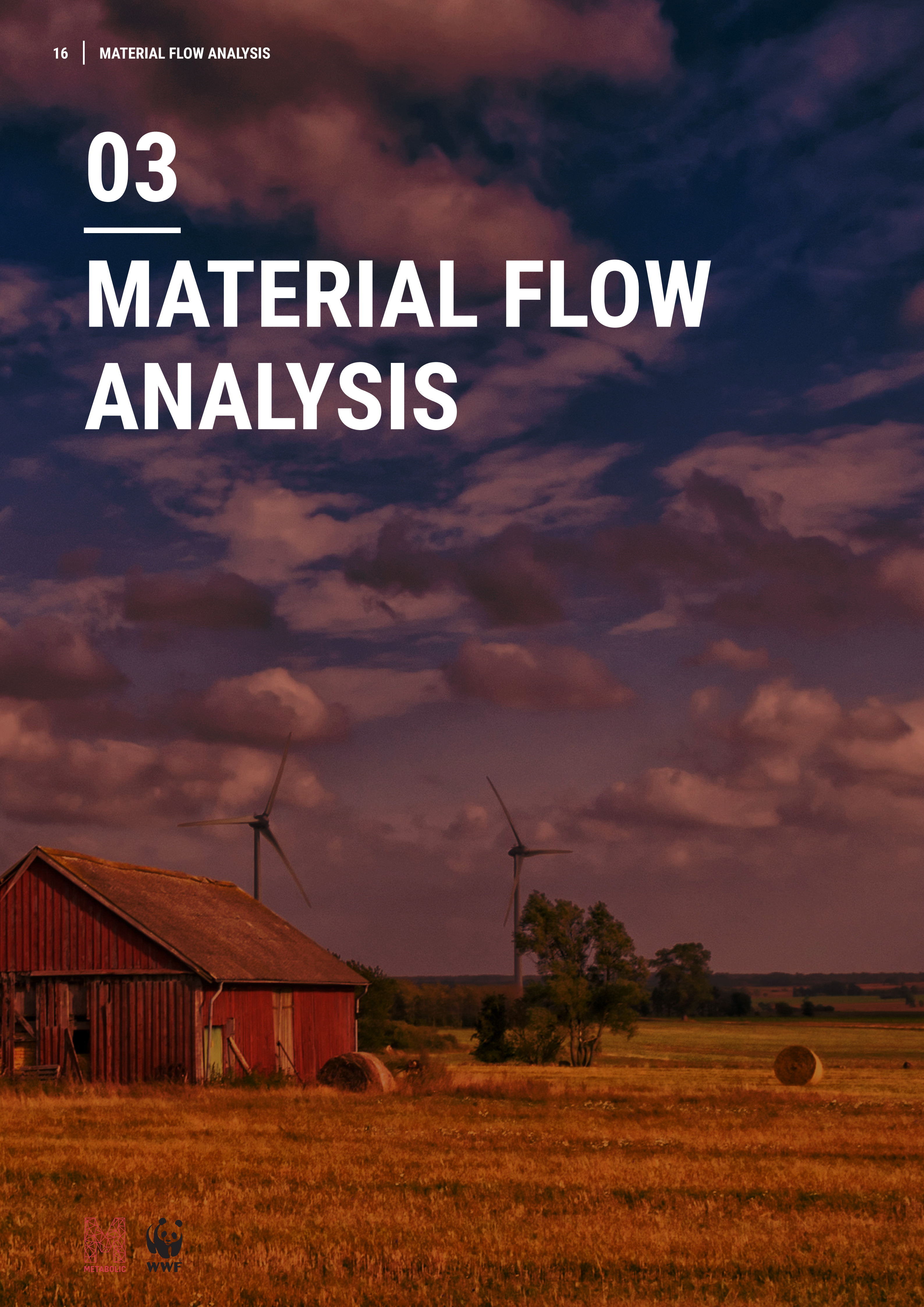
Phosphorus is an essential element for all living beings. The majority of the world's agriculture relies on fertilizers derived partially from the non-renewable phosphate rock. According to Cordell (2009, 2011), a fundamental point when considering the available phosphate in relation to food security, is that the amount of phosphorus actually accessible for use is much smaller than the amount of resources estimated in the ground.

This is due to a range of physical, ecological, technical, geopolitical, social, and legal limitations in accessing it (Cordell, 2011). Peak resource theory postulates that a 'peak' in the production of the commodity will occur long before 100% of the reserve is theoretically depleted, and after this point, resource extraction will become increasingly more expensive as the number of accessible reserves are depleted (Cordell, 2011). For phosphorus, estimates range from peak mining in 2030 (Cordell et al 2009) to reserves going beyond 2100 (van Kauwenbergh, 2010).

Additional to the challenge of resource scarcity, there are many environmental impacts associated with the production and use of phosphorus. These impacts occur across a range of spatial scales from mining, to agricultural fields and hydrological pathways, to post consumption emissions, as well as temporal scales on the short, medium and longer term.

- The exploration and mining of phosphorus impacts the immediate natural landscape and ecosystems. Local disturbances, air emissions, water contamination, noise, and vibration all occur where the mine is located (UNEP, 2001).
- The greatest environmental impact, associated with fertilizer production and processing, is the generation of phosphogypsum stockpiles during processing of phosphoric acid (phosphate rock reacted with sulphuric acid) (IFA, 2009).
- Although crops use the nutrient with relatively high efficiency, lost phosphorus that reaches water is commonly the main cause of eutrophication (Carpenter, 2011). Eutrophication in aquatic systems causes algae and cyanobacteria to grow rapidly and form blooms. The decomposition of dead algal and cyanobacterial cells by bacteria depletes the supply of dissolved oxygen in the water, potentially suffocating fish and other aquatic organisms. Excessive blooms on the surface of a lake or river can block sunlight from penetrating the water, choking out beneficial submerged aquatic vegetation.
- Many algal and cyanobacterial blooms can produce toxins that can cause health issues in humans and animals, including stomach aches, vomiting, diarrhea, and more.
- Phosphorus flow to the oceans is a key driver of marine anoxia. A sustained increase of phosphorus flowing into the oceans exceeding 20% of the natural background weathering was enough to induce past ocean anoxic events. This is estimated to be approximately eight times the natural background rate of influx. Records of Earth history show that large-scale ocean anoxic events occur when critical thresholds of phosphorus inflow to the oceans are crossed (Handoh et al., 2003).

It is clear that there will be a decline in the amount of virgin phosphorus available for food production, and that it is absolutely critical to maintaining food production. Therefore, it is prudent to investigate whether and how much phosphorus is currently available in the Baltic food system for capture and reuse, both to increase resource security and to reduce the environmental impacts of nutrient surpluses and losses.



03

MATERIAL FLOW ANALYSIS

While the environmental impacts of nitrogen and phosphorus are related, the motivation for assessing the potential for increased circularity differs. For phosphorus, we want to reduce the environmental impacts and increase the security of a critical resource. For nitrogen, it is more focused on the environmental impacts associated with a continual loading of new nutrients into the system, to stay within the safe operating space for the ecosystems of the Baltic Sea region. To understand the circularity potential within the system, we must conduct an analysis of how the nutrients are currently moving through the system, providing insight of where the nutrients come from, where they flow through the system and where they end up.

The method used for this is called a Material Flow Analysis (MFA), which is defined as a systematic assessment of material flows and stocks within a system with a clearly defined scope in terms of space and time (Brunner & Rechberger, 2004). This method is an important first step in a systems analysis aiming to map out and quantify resource flows. The results form the baseline for finding effective leverage points and for prioritizing possible interventions.

The first step of the analysis was to define the boundaries of the system, i.e., what is included in the analysis. In the following step, we followed the approach of Giljum & Hinterberger (2004) and mapped the materials that are used as inputs into the analyzed system. Then, we analysed the flows of turning these materials into products and finally into outputs.

This process is often visualized in the form of a Sankey diagram (Figure 3). This diagram shows from which sources a 'flow' comes from (on the left), how it is used or transformed within the system (center), and how the 'flow' eventually leaves the system and becomes an output (on the right). A key output of a material flow analysis visualized in a Sankey diagram is the identification of opportunities to create systemic change known as "hotspots".

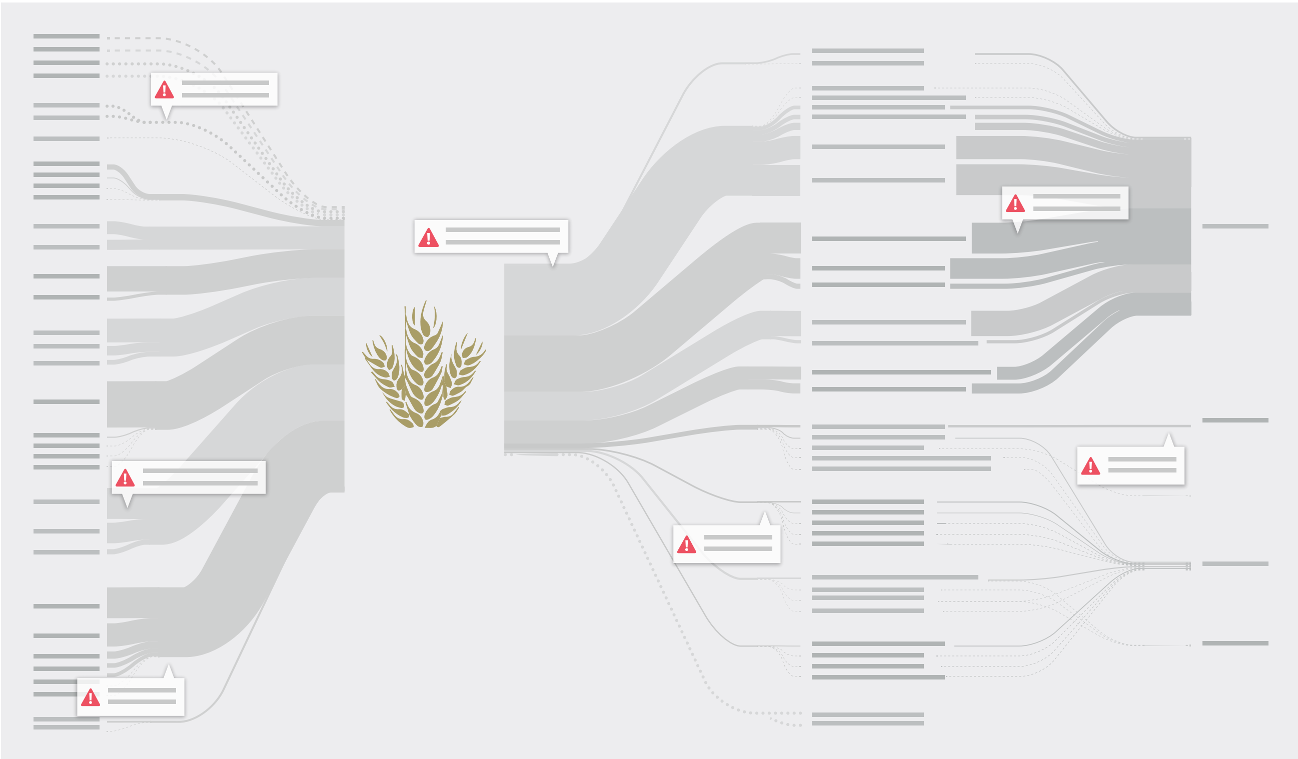


Figure 3. The different elements in a Sankey diagram

The Flows of Nitrogen and Phosphorus by Core Agrifood Typologies in the Baltic S

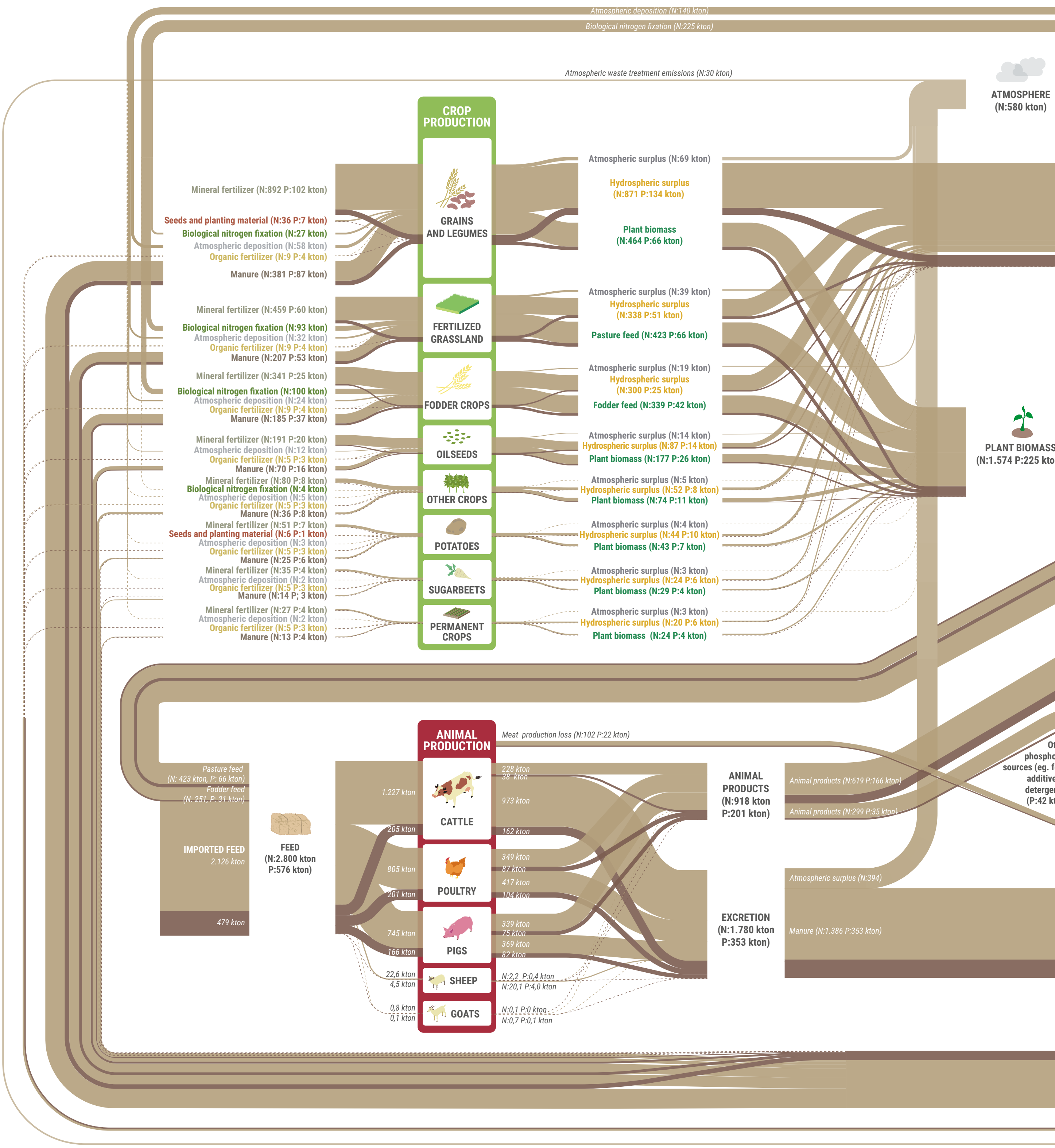


Figure 4. Nutrient flows according to crop and animal production. A larger, high-resolution version can be viewed here.

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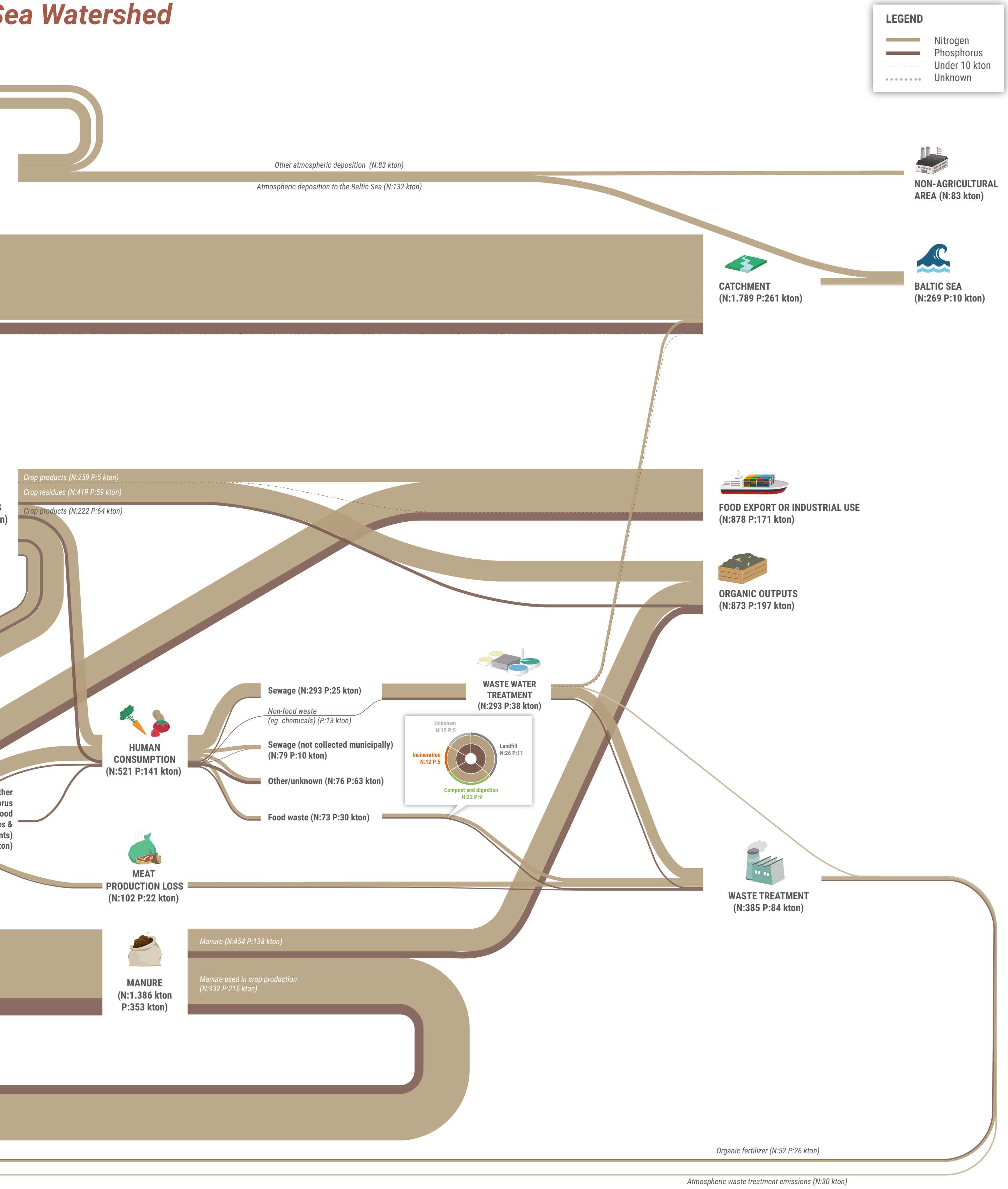
Sea Watershed



The Flows of Nitrogen and Phosphorus by Country in the Baltic Sea Watershed

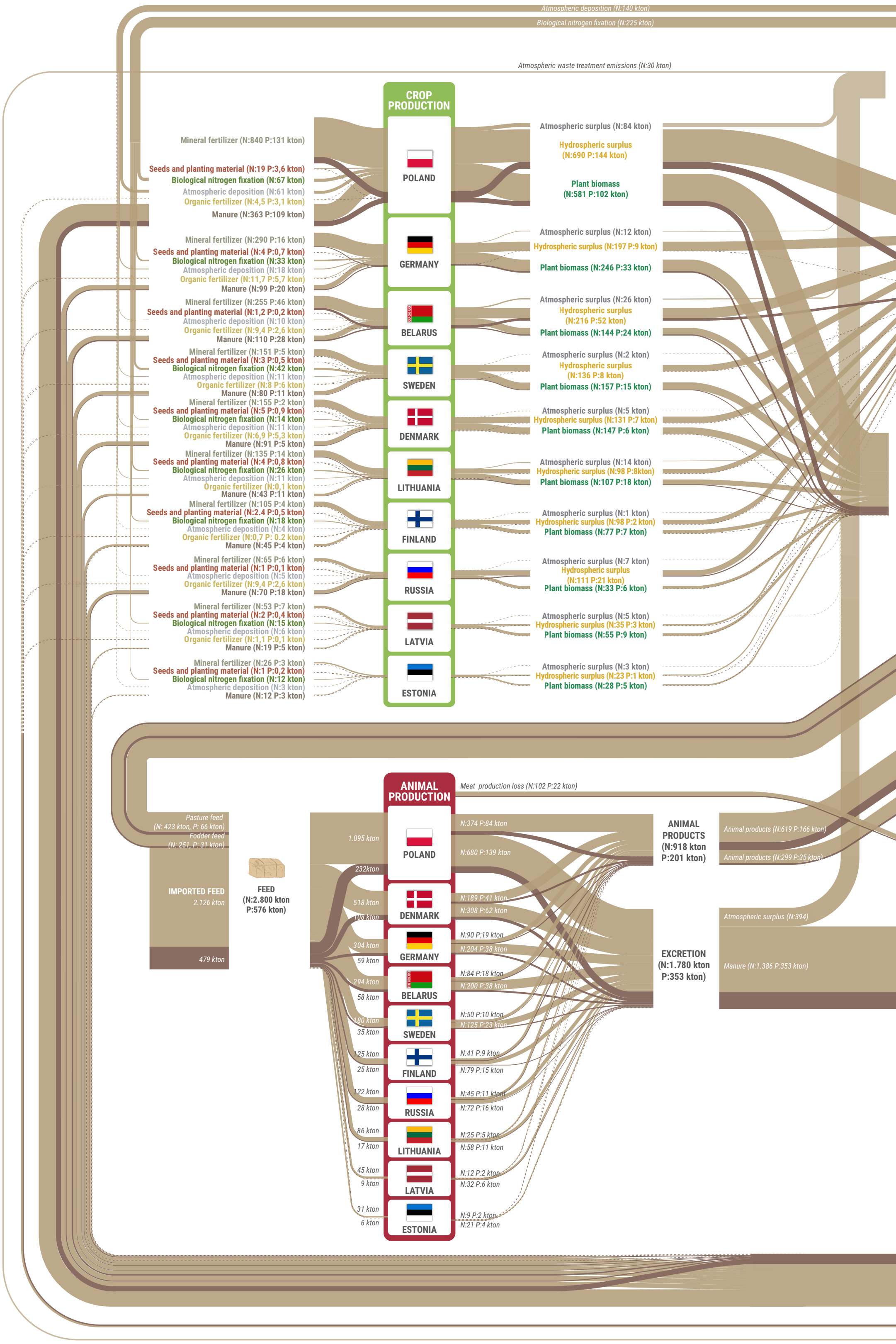
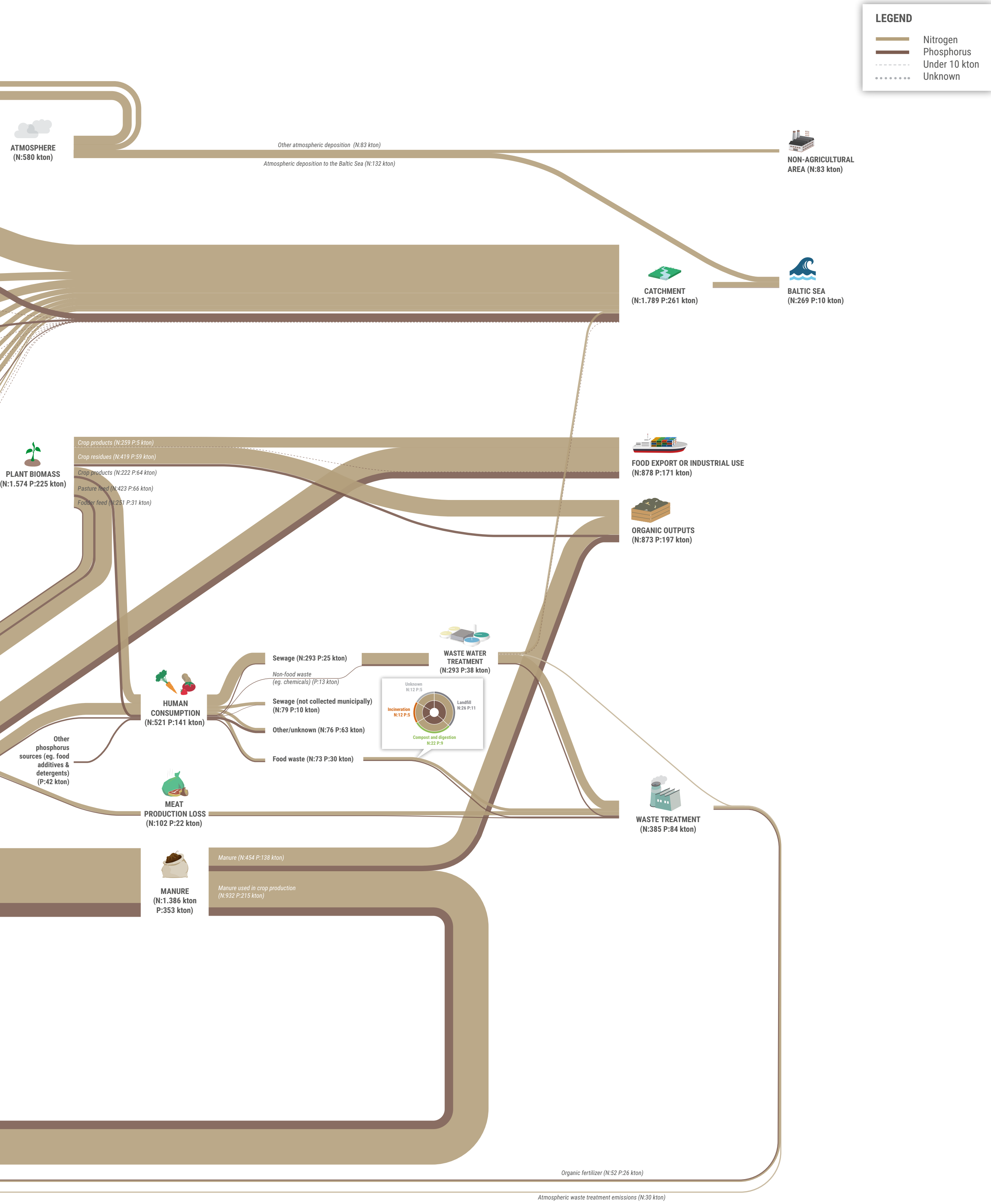


Figure 5. The country-level nutrient flows. A larger, high-resolution version can be viewed here.


LEGEND
Nitrogen
Phosphorus
Under 10 kton
Unknown
ATMOSPHERE (N:580 kton)
Other atmospheric deposition (N:83 kton)
Atmospheric deposition to the Baltic Sea (N:132 kton)
NON-AGRICULTURAL AREA (N:83 kton)
CATCHMENT (N:1.789 P:261 kton)
BALTIC SEA (N:269 P:10 kton)
PLANT BIOMASS (N:1.574 P:225 kton)
Crop products (N:259 P:5 kton)
Crop residues (N:419 P:59 kton)
Crop products (N:222 P:64 kton)
Pasture feed (N:423 P:66 kton)
Fodder feed (N:251 P:31 kton)
FOOD EXPORT OR INDUSTRIAL USE (N:878 P:171 kton)
ORGANIC OUTPUTS (N:873 P:197 kton)
HUMAN CONSUMPTION (N:521 P:141 kton)
Sewage (N:293 P:25 kton)
Non-food waste (eg. chemicals) (P:13 kton)
Sewage (not collected municipally) (N:79 P:10 kton)
Other/unknown (N:76 P:63 kton)
Food waste (N:73 P:30 kton)
WASTE WATER TREATMENT (N:293 P:38 kton)
Unknown N:12 P:5
Landfill N:26 P:11
Incineration N:12 P:5
Compost and digestion N:22 P:9
Other phosphorus sources (eg. food additives & detergents) (P:42 kton)
MEAT PRODUCTION LOSS (N:102 P:22 kton)
WASTE TREATMENT (N:385 P:84 kton)
MANURE (N:1.386 kton P:353 kton)
Manure (N:454 P:138 kton)
Manure used in crop production (N:932 P:215 kton)
Organic fertilizer (N:52 P:26 kton)
Atmospheric waste treatment emissions (N:30 kton)

Setting a Systems Boundary

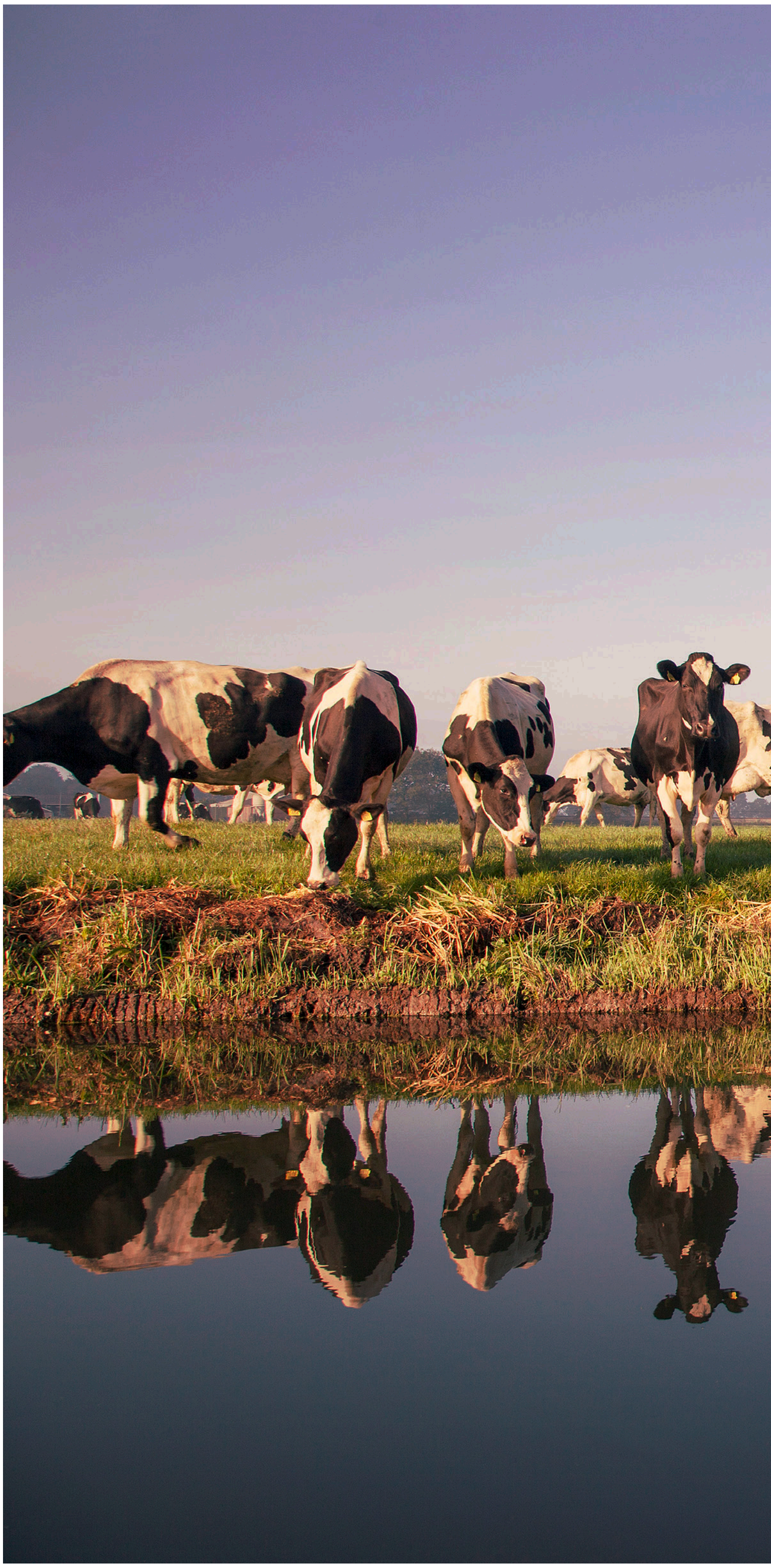
In this case, we analyzed the current agri-food system in the Baltic catchment area in terms of what inputs enter the region, how these inputs are distributed and consumed, and what happens to them after the consumption. The inputs analyzed in this case were the flows of nitrogen and phosphorus. The specific geographic boundaries of the Baltic catchment area were harmonized with the definition used by Hong et al., (2017) and Svanbäck et al., (2019) equaling a total of 49 administrative-accounting units (38 NUTS2 regions for the EU countries and 4 oblasts for Belarus and 7 oblasts for Russia). With this approach, countries collectively representing about 3% of the catchment area, namely Norway, Ukraine, Czech Republic, and Slovakia, were not included in this study.

Multi-Perspective Approach

In order to get a good overview of the system, we analyzed the nutrient flows from two different perspectives. First, we mapped the whole Baltic Sea catchment areas in terms of the nutrient flows according to different types of agriculture (Figure 4). We aligned the categories used with existing nutrient flow research in the Baltic sea area and Europe (Hong et al., 2012; Svanbäck et al., 2019; Grizetti et al., 2007). The crop production types we analyzed were grains and legumes, fertilized grassland, fodder crops, oilseeds, potatoes, sugar beets, permanent crops, and other crops. The animal production types that we analyzed were cattle, poultry, pigs, sheep, and goats. These higher-level categories were aggregated from multiple subcategories both in terms of animal and crop types as well as in terms of geographical units. The sub-categories, and the methodology in more detail can be found in *supporting documents*.

Next to the crop and animal production, we also mapped the country-level nutrient flows from the perspective of the ten countries (Figure 5). The primary analysis unit was the 49 administrative-accounting units that were in the end aggregated to the country level.

After having visualized the flows in the two Sankey diagrams, we conducted further research into the context and impacts of nutrient flows to provide insights into hotspots and leverage points in the system. These are visualized as text boxes in the Sankey diagrams. In the following chapter, we discuss the most important hotspots.



04 RESULTS

LARGE NUTRIENT LOSSES OCCURRING

Across the entire basin, fully 50% of nitrogen and 53% of phosphorus applied on the fields is not taken up by crops.

While average plant uptake rates differ from crop to crop and soil type to soil type, these figures show that there is a surplus of nutrients being applied to soils. From this we can infer that through better nutrient management and storage, there could be a reduction of nutrients lost to leakage, and a reduction in the nutrients being applied. According to McCrackin (2018), some regions of the Baltic have a sufficient supply of phosphorus already available in soils, which also offers opportunities for reduction in application.

ADDITIONAL NUTRIENTS ARE CONSTANTLY BEING ADDED TO THE SYSTEM

When analyzing the nutrient flows in the system, one of the main findings is that additional nutrients are constantly introduced in large quantities in the Baltic Sea area agri-food system. The two main sources of additional nutrients are mineral fertilizers and manure derived from imported animal feed (Figure 6).

This figure relates to the relative proportion of locally produced and imported animal feed. The nutrients in the imported feed are consumed by animals, and their manure is applied to crops, where they are either taken up or lost (figures 7 and 8 - main crop MFA).

Outside of manure and fertilizers, the remaining nutrients applied are in organic fertilizers, seeds and planting material, atmospheric deposition, and biological nitrogen fixation. Organic fertilizer is defined in this report according to the Eurostat (2013) dataset "consumption of fertilizers except for manure," and includes all organic fertilizers such as compost, sewage sludge, and industrial waste excluding manure.

Since a large proportion of the nutrients in manure are currently being introduced as new nutrients into the system through the animal feed, only a small proportion of the nutrients are actually cycled within the system between the crop production and animal production and back to crop production. Differentiating between cycled nutrients in crop and animal production (manure from cycled & organic fertilizer) and those that are introduced (imported feed and mineral fertilizer), we see that only 9% of nitrogen and 13% of phosphorus is cycled while 91% of nitrogen and 87% of phosphorus is introduced. From this we can say that there is a huge potential for an increase in nutrient cycling in the region.

Across the entire basin, fully 50% of nitrogen and 53% of phosphorus applied on the fields is not taken up by crops.

The two main sources of additional nutrients are mineral fertilizers and manure derived from imported animal feed (Figure 6).

Figure 6. Nitrogen and Phosphorus inputs and outputs to crop production.

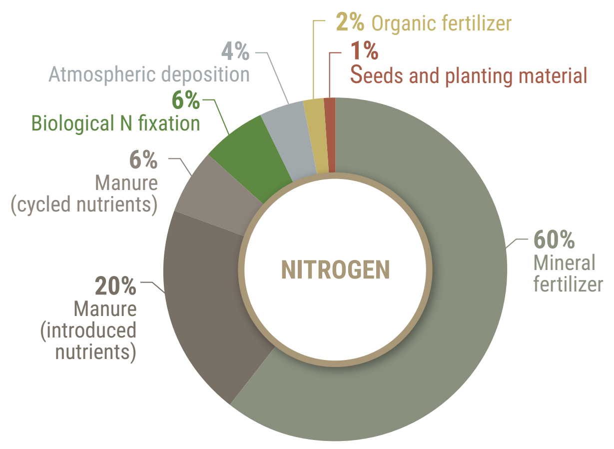


Figure 7: Sources of nitrogen flowing into crop production.

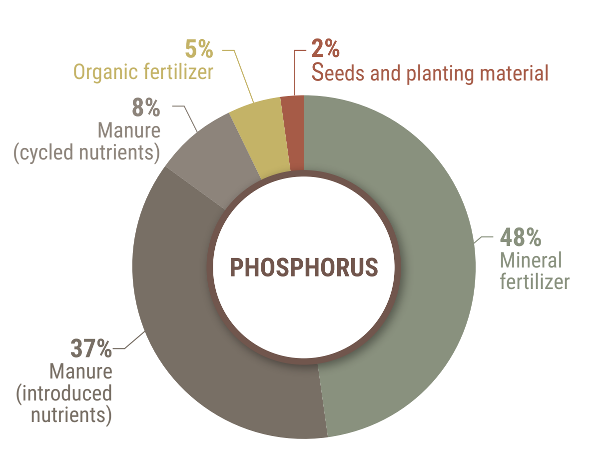


Figure 8: Sources of phosphorus flowing into crop production.

Only 9% of nitrogen and 13% of phosphorus is cycled while 91% of nitrogen and 87% of phosphorus is introduced. From this we can say that there is a huge potential for an increase in nutrient cycling in the region.

CIRCULAR ECONOMY AND CIRCULAR AGRICULTURE

The circular economy emerged with the aim to reduce resource consumption, throughput, and emissions to the environment by closing material loops within the economy (Jurgilevich et al., 2016).

The WWF defines the circular economy as:

"A regenerative system, driven by renewable energy that replaces the current linear 'take-make-dispose' industrial model. Materials are instead maintained in the economy, resources are shared, while waste and negative impacts are designed out. A sustainable Circular Economy creates positive environmental and society-wide benefits and functions within planetary boundaries, supported by an alternative growth and consumption narrative."

Circular Agriculture is an application of the principles of the circular economy to an agricultural context. Agriculture has historically relied on nutrient recycling to maintain productivity. However, since the Green Revolution in the mid- 20th century, the cycling of nutrients has become less important as mineral fertilizers have become cheap and freely available, incentivized by market and policy under the EU Common Agriculture Policy. As mentioned, the implications of this are nutrient surpluses, altered biogeochemical cycles, and severe ecological impacts which are additionally compounded by climate change. Circular agriculture grew out of the need to address the linearity of agricultural production with the tools of a circular economy.

Three principles of circular agriculture are proposed by de Boer and Ittersum(2018), which focus on the hierarchy of material use in the agricultural system. They are:

Principle 1

Food is mainly composed of plant biomass, and the consumption of this food by humans rather than animals should be prioritized.

Principle 2

By-products from crop and animal production, food processing, and consumption are recycled back into the system.

Principle 3

Animals are fed with plant products that are not suitable for humans.

Applying circular agriculture means capturing excess nutrients and returning them to the food system. Current trends in agriculture in some parts of the catchment area include consolidation and specialisation, resulting in larger farms with more intensive production practices than in the past. This results, in some cases, in localized nutrient surpluses (Fammler et al., 2018). Implementing circularity in agriculture can be challenging, as activities are distributed in rural and peri-urban areas. However, the concentration and intensification of production in some landscapes offers opportunities for better capture and cycling of manure, for example between animal and crop production. Additionally, there are underutilized nutrient resource concentrations associated with human consumption and municipal waste treatment.

SYSTEMIC SURPLUS OF NUTRIENTS

We see from our analysis that there are 1258 kilotons of nitrogen and 281 kilotons of phosphorus within the system that are currently under-utilised. This represents 61% of the total added mineral nitrogen and 121% of the total fossil phosphorus applied to crops for fertilization. This figure is made up of nutrients that are found in waste (covering food, sewage, and meat production waste), and in other organic outputs.

The nitrogen and phosphorus content of the food waste generated in the Baltic Sea catchment area contains 73 kilotons of nitrogen and 30 kilotons of phosphorus (Figure 9).

The food waste produced in the Baltic Sea catchment area could replace 10% of the nitrogen and 18% of the phosphorus of the yearly food intake of the pigs in the catchment area. This provides an important opportunity for nutrient recycling within the system. However, it is important to understand the systemic trade-offs between competing uses of food waste, such as biogas production or incineration.

Next to food waste, recycling of nutrients from sewage could provide an important resource. We found that within the Baltic Sea catchment area, there is 293 kilotons of nitrogen and 38 kilotons of phosphorus in the sewage flow. As phosphorus is a finite resource, it is important to capture it from waste water and from sewage sludge.

61% of the total added mineral nitrogen and 121% of total fossil phosphorus is currently under-utilized.

The food waste produced in the Baltic Sea catchment could replace 10% of the nitrogen and 18% of the phosphorus of the yearly food intake of the pigs in the catchment area.

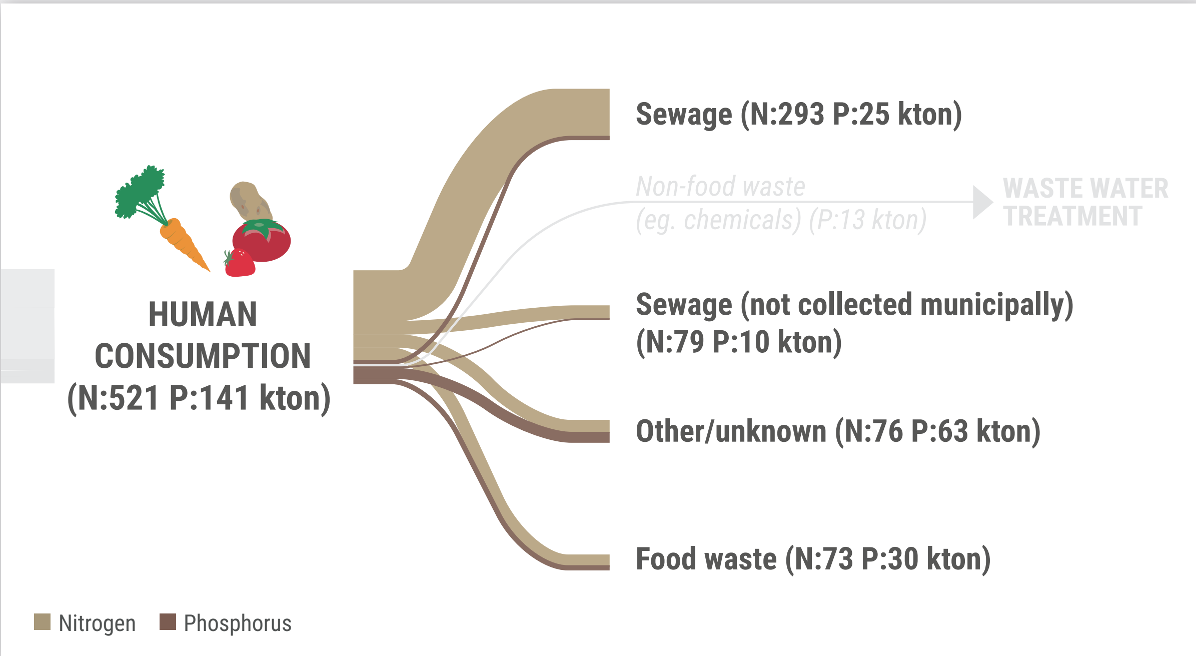


Figure 9. The production of food waste in the Baltic Sea catchment area.

Today, only approximately one-third of the collected sewage sludge in the Baltic Sea catchment area is used in crop production (Baltic Eye, 2017).

According to Rosemarin and Ek (2019), ecotechnologies for phosphorus recapture that are currently available include crystallisation processes applied to liquid from sludge dewatering, phosphorus recovery from incinerated sewage sludge ash, phosphorus recovery from sludge, struvite recovery and reuse from digested sludge, and anaerobic digestion of livestock manure. More innovation and market uptake are still needed to effectively recycle nutrients from sewage sludge. Additionally, there are legislative barriers to the utilization of sewage sludge in some Baltic countries which stand in the way of the full use of these resources.

Our analysis shows that there are nutrients within manure and crop residues that are unused. One of the most probable reasons for the under-utilization of manure is the local over-fertilization (McCrackin et al., 2018).

Crop residues, which contain a large amount of nutrients (690 kilotons of nitrogen and 97 kilotons of phosphorus), are potentially also underutilized. It is not clear from our analysis where these residues are ending up. Possible uses are spreading over fields as mulch, or used as fodder, fibre, feedstock, fuel or further use such as compost production (Gobin et al., 2011). Further research is needed to better understand the opportunities of the nutrients in crop residues on a country- or regional level in order to find an optimal use for the different types of crop residues that benefit the system at large.

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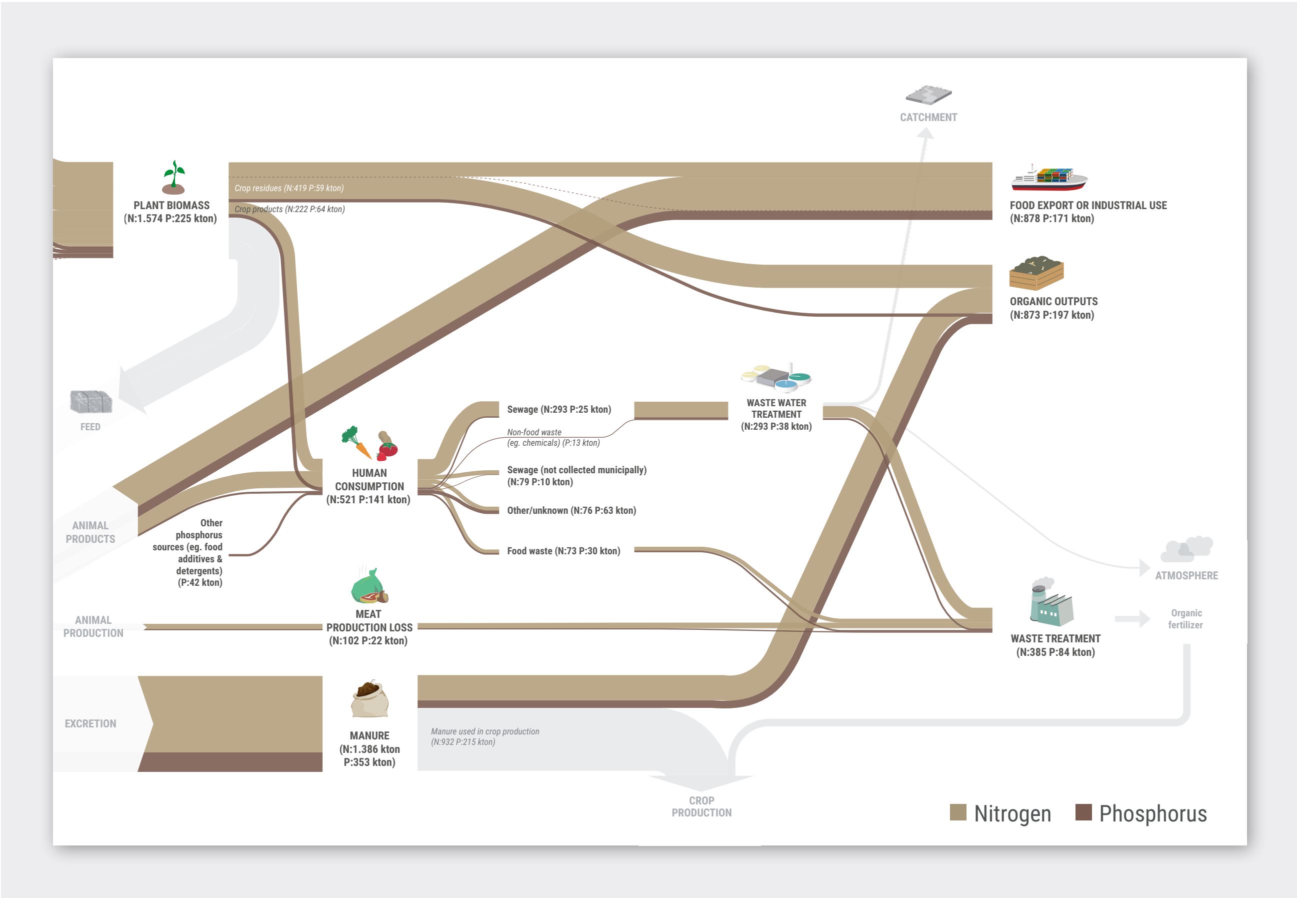

Figure 10. The flows of manure and crop residues leading to organic output.

UNDER AND OVER-SUPPLY OF MANURE

As animals consume feed, the nutrients within the feed either become part of the animal, and eventually animal products, or are excreted.

When comparing the proportion of the nutrients that are being transformed into animal products and those that end up in manure, we find that cattle excrete a larger proportion of nutrients than other livestock (Figure 11).

The large proportion of nutrients ending up in manure is a valuable resource for farmers. With improved manure handling, around 10% of nitrogen up to 30% of fossil phosphorus in the imported mineral fertilizers could be replaced, and would go a long way to meeting the HELCOM targets (McCrackin (2018).

However, in areas with a high livestock density, there are problems with nutrient oversupply and leakage, and in areas of low density, there is undersupply. Therefore, to improve the potential for the cycling of animal manure, it is critical for land-use planners to achieve an appropriate balance between animal density and local crop production areas, and for there to be more integration of crop and animal production in terms of feed supply and manure use. Moreover, processing the manure to a form that is more easily transported, could enable the provision of manure to areas of undersupply (Svanbäck et al., 2019).

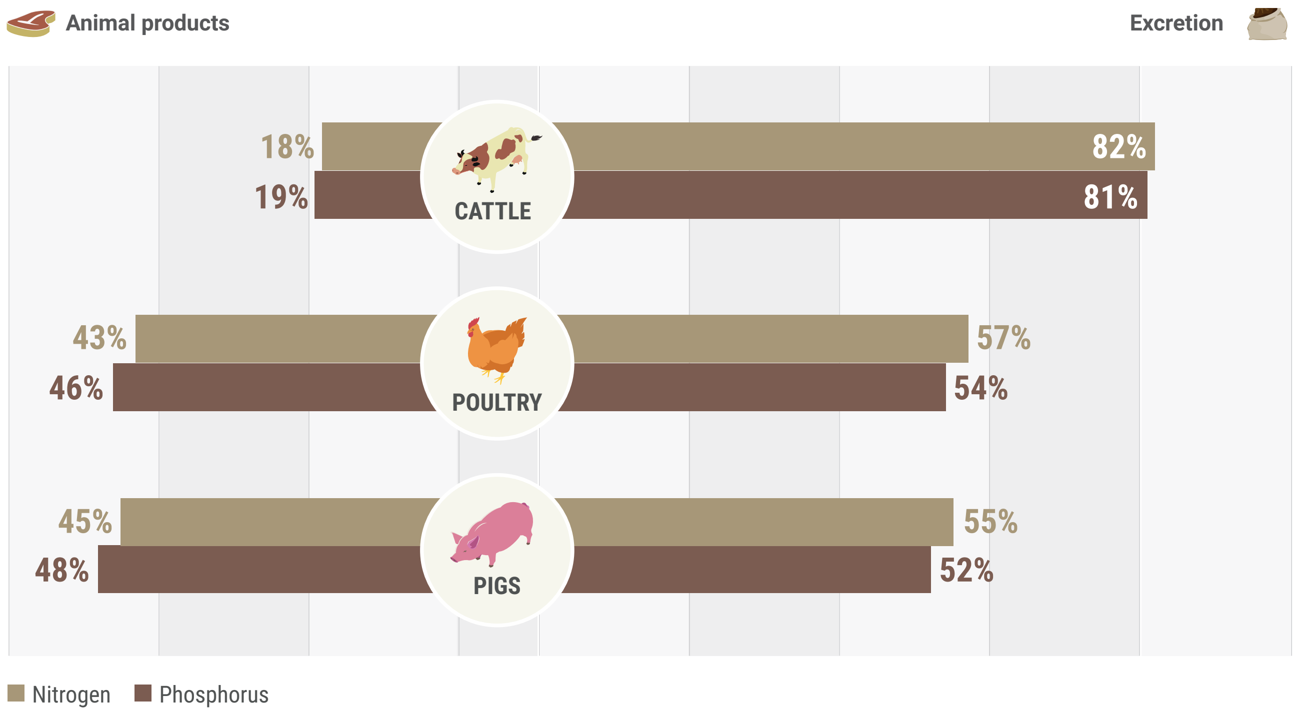

Figure 11. Proportion of nutrients in the two main output sources of the animal production.

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05

STAKEHOLDER ENGAGEMENT

On November 25th and 26th 2019, Metabolic and the WWF steering group hosted a workshop with key stakeholders from the Baltic food system to communicate our results, and to co-develop a vision for a Baltic Food System that cycles nutrients and other materials more effectively. We invited the stakeholders to apply their expert knowledge and experience to our analysis, and help us identify research gaps. We also asked them to think about how the characteristics of the Baltic food system could support circularity, what existing platforms and programs we should build on, and how circularity could support mitigating some of the issues around the oversupply of nutrients. The following pages outline the outcomes of the engagement, which will be used as a starting point for the WWF to work towards developing a more circular and collaborative Baltic food system.

RESEARCH GAPS

Participants in the workshop identified the following research gaps in the analyzed nutrient flows. Including data for these nutrient flows could help in identifying additional opportunities for nutrient circulation in the agri-food system of the Baltic Sea catchment.

Assessing food imported from outside the Baltic Sea catchment area

Inclusion of a separate nutrient flow for imported food was suggested by the workshop participants. However, as our study area includes 49 different administrative accounting units in 10 different countries, distinguishing between the inter-study area flows and the import flows from outside the study area was deemed outside of scope. Instead, we mapped the nitrogen and phosphorus flow of all consumed food items (both internal and imported ones) at the human consumption node using EU average statistics. However, if a country-level focus were conducted in the future, adding the import flows would be feasible and interesting from the perspective of clearer insights into both nutrient recycling and self-sustenance.

A full catchment approach is necessary

In the present study, Norway, Czech Republic, Slovakia, and Ukraine were not included in the study area, as these countries cover less than 3% of the catchment area. In addition, this decision was taken in order to harmonize the study with the existing data by the leading nutrient flow scientists in the Baltic Sea area, such as Hong, Svanbäck, and McCrackin.

The workshop participants suggested the inclusion of all the Baltic Sea catchment area countries in the nutrient flow analysis in order to better understand the baseline of these countries to facilitate the future dialogue and collaboration.

We need a better understanding of resource competition

One key challenge when considering linear material and nutrient flows as resource opportunities, is to understand the optimal use pathways for them. In our analysis, food waste, human waste, organic materials, and crop and animal residues were all identified as potential opportunities for nutrient extraction for sustainable agriculture practices. However, there are many competing uses for both plant and animal residues for use in the bioeconomy. A clear assessment of the limits of supply within the food system in the Baltic and a trade-off analysis of the competing uses for resources would be appropriate before recommendations for increased circularity opportunities in the system can be made.

Economic considerations must be addressed

Recent analysis on the value at risk in the Baltic suggests that ecological dynamics in Baltic Sea will be increasingly costly to the economic sectors dependent on them due to, among other things, climate change (Shaw et. al, 2019). More investigation is warranted as to the implications of not acting to capture nutrients now, and potentially having more costly measures in the future relating to ecosystem changes or resource scarcity.

Horse keeping, pets, and other forms of animal husbandry need to be assessed

Guidelines for horse farms are lacking both in the Baltic Sea Action Plan and in the EU Water Framework Directive (Parvage et al., 2015) despite an increase in horse keeping during the last decades (Keskinen et al., 2017). Around 3 - 6% of the agricultural land of the Baltic Sea countries is used for horse keeping (Parvage et al., 2015). The manure that these horses are producing constitutes a substantial nutrient resource.


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Keskinen et al. (2017) calculated that over 300 million kg of nitrogen and 48 million kg phosphorus is excreted yearly by horses within the European Union. Horse manure should be better connected to crop production, and proper manure management guidelines for horse keeping should be introduced (Keskinen et al., 2017). The analysis of the nutrient flows related to the horse farming in the Baltic Sea catchment should also be prioritized.

Inclusion of the nutrient flows associated with pets and other forms of animal husbandry, such as fur farms in Finland, was suggested by the workshop participants. However, there is currently no data on these nutrient flows for the Baltic Sea catchment countries. Hobbie et al. (2017) analyzed urban watershed nutrient budgets in St. Paul, Minnesota and found that dog waste contributed up to 76% of total household phosphorus inputs to the urban watershed and up to 28% of total household nitrogen inputs. Some of the other major household nutrient input sources to the urban watershed included residential fertilizers and atmospheric deposition. More data on the nutrient flows associated with pets are needed especially for urban and peri-urban settings, where they could also provide a key nutrient capture opportunity.

In Finland, fur production is concentrated in an area with a high density of other forms of livestock production. According to Luostarinen et al. (2017), it is important to understand better the specific manure content and nutrient flows of the fur animals to use their manure in an efficient way. Work is ongoing in the HELCOM AGRI working group to estimate the contribution of manure from fur farms and other forms of animal husbandry, and this data should be incorporated once it is available.

The existing direction on manure handling across the Baltic Sea Region for horses, sheep, goats, and in fur farming is patchy and inconsistent, and frequently based on voluntary guidelines. Given how these animals are often widely distributed in rural areas, either in an agricultural setting or frequently as a hobby or recreation activity, introducing new practices and encouraging more awareness maybe challenging. Developing recommendations through HELCOM to support development of national strategies for manure management can help curb nutrient flows to the Baltic from this wide range of animal inputs, and offer opportunities for nutrient capture and cycling.

A WORKING VISION FOR A CIRCULAR BALTIC AGRI-FOOD SYSTEM

Participants in the workshop were presented with a draft vision which captures what a circular agri-food system for all in the region could entail. This vision was discussed and critiqued, and participants co-created a shared vision to frame further development and collaboration in this area:

"The Baltic Sea catchment area is supported by a circular and resilient food production system that uses resources efficiently while promoting healthy soil and securing animal welfare. Sustainable nutrient management contributes to the productivity of agriculture, to a Baltic Sea in Good Ecological Status, to an increase in biodiversity, and to supporting the 1.5-degree climate targets according to the Paris Agreement."

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Ways Forward for Increased Cycling of Nutrients

Next, participants developed goals around this vision, and developed propositions for concrete activities which would lead to both increased nutrient cycling, and a reduction of the environmental impacts of nutrients in the region. Participants prototyped roadmaps for these activities, and and identified stakeholder groups within the region to engage with for their initiation. Below is a summary of their output.

Develop standardized nutrient booking and data infrastructure for the catchment area

While nutrient bookkeeping is mandatory in almost all Baltic states, there is so far not a consistent and harmonised system. Therefore, it was recommended that mandatory, standardized nutrient bookkeeping be legislated for in the basin. This would enable the clear tracking and record keeping of nutrient use and flows, to allow for adaptive decision making to mitigate problematic areas at a more granular scale. Additionally, this policy should support the development of a common data infrastructure to inform and support decision making, and to connect to existing platforms linked to water and air quality.

There are opportunities for this to be integrated into existing policy frameworks, for example the EU Common Agricultural Policy. However regional frameworks such as the HELCOM might be a more appropriate pathway considering the greater coverage in the catchment area and momentum from the convention so far on the topic.

Classify horse keeping as agriculture

As discussed, horsekeeping consumes fodder and feed, produces manure, and is an important land use, especially around urban areas. Currently, it is difficult to capture the flows associated with horse-keeping due to gap/mismatch in statistical reporting. It is therefore important for data for horse keeping to be integrated into agricultural reporting, and horsekeeping itself to be classified as an agricultural land use.

Build on existing collaborations and success stories with farmers

During the workshop, the participants indicated that current collaborations and success should be built upon to test new approaches and scale activities for reducing nutrient input to the system and for capturing and utilizing nutrient flows. The knowledge is for the most part in place, therefore effort should go into developing more action through collaboration. Examples of activities that can reduce nutrient input and runoff are increasing production of local feed and fodder, catchment approaches to allocating nutrient budgets, and improving the quality of feed and fodder to reduce leakage through manure.

Mineral fertilizers should be recycled and carbon neutral

It is clear that mineral fertilizers have an important role to play in food production. In line with the proposals from Earth system science for local limits on nutrient inputs, mineral fertilizer should, insofar as possible, be produced with recycled nutrients. According to McCrackin (2018) by improved manure handling alone, up to 30% of phosphorus and 10% of nitrogen could be replaced with cycled nutrients. To reduce the considerable environmental impacts around the production of mineral fertilizers, all non-cycled and cycled should be produced carbon-neutral. The mineral fertilizer industry has a role to play in developing these technologies.

Technology & innovation for nutrient capture must be supported

Innovating for the processing and capture of nutrients from all the streams available, including human and food waste need to be enhanced to close the loop on nutrient cycles. Great examples are already in place, such as capturing of nitrogen from point emissions, and phosphorus from waste-to-energy incineration plants, and the production of animal feed from food waste through insect production. These and other new technologies need assistance to scale up and to be plugged into existing infrastructures around waste treatment.

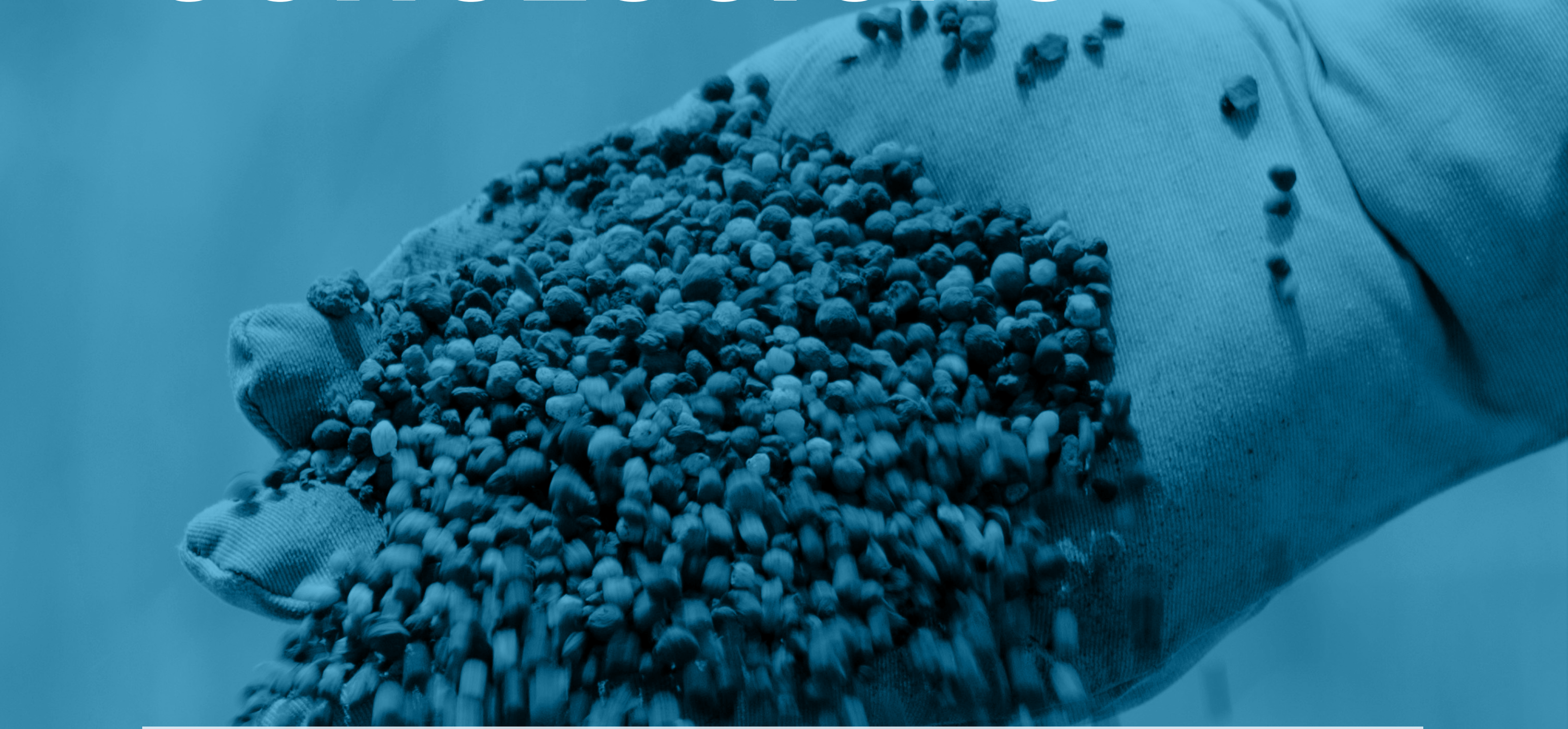
Civil society must continue to advocate and convene

Civil society has an important role to play as a convener, in creating knowledge platforms and complementary instruments, and in developing partnerships and collaborations to accelerate the transition into a circular and resource efficient food system.

Consumers must be made more aware

Consumers play a critical role in any food system. Participants in the workshop agreed that there is a need for better communication to consumers to build awareness of the issues around nutrient management. Building consumer awareness can increase the demand for more nutrient friendly products, in connection to other already on the agenda topics such as climate change. One option proposed in the workshop is to include good nutrient management at the production level in existing certification schemes in the region.

06 CONCLUSIONS



In this analysis, we have identified clear opportunities for nutrient capture and cycling from food and animal production waste, and from sewage sludge that would represent a sizable proportion of the total nutrient needs of the region. The improved handling of manure could address the oversupply of nutrients in some areas, and the oversupply in others. Additionally, there are still many gaps in knowledge of sources of nutrients, such as in animal husbandry.

To access these resources, and to reduce the environmental impacts of excess nutrients in the Baltic food system, investment and collaboration will be key, with farmers, retailers, NGOs, policy-makers and land planners all having key roles to play. A standardized bookeeping framework across the region would enable a granular understanding of local nutrient use and leakage. Technology, when scaled, can also address key challenges in nutrient capture from waste. Consumers have a key role to play, and new markets must be created to create value out of good nutrient management at the farm level.

The catchment area, inclusive of fourteen countries, is highly complex in terms of governance, ecology, economy, infrastructure, and cultural aspects. A far more inclusive and in-depth stakeholder process is required, along with a clear framework for understanding systemic dynamics, before we can make specific prescriptions towards a more circular system.

However, this project was an important first step in assessing the current state of nutrient flows within the system, communicating the results with key stakeholders, identifying research gaps and potential ways forward to a more sustainable and circular agri-food system in the Baltic.

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COLOPHON

Commissioned by WWF Sweden

AUTHORS AND RESEARCH TEAM:

Brian Shaw
Heidi Lampén

GRAPHIC DESIGN:

Marta Sierra García

ADDITIONAL RESEARCH:

Ilaha Abasli
Andrew McCue
Pieter van Exter
Antoine Coudard
Robert Burkhardt
Sokratis Oikonomidis
Parkpoom Kometsopha

PROJECT STEERING GROUP:

Elin Bergman
Camilla Välimaa
Anu Suono
Valerie de Liedekerke de Pailhe
Jenny Jewert
Anna Richert

WORKSHOP PARTICIPANTS:

Helena Aronsson, *Swedish University of Agricultural Sciences (SLU)*
Jens Berggren, *Federation of Swedish Farmers (LRF)*
Elin Bergman, *WWF SE*
Valerie de Liedekerke de Pailhe, *WWF*
Sara Ekström, *Yara AB*
Pieta Jarva, *Baltic Sea Action Group*
Jenny Jewert, *WWF SE*
Pär Larshans, *Ragn-Sells*
Anna-Karin Modin Edman, *Arla Foods*
Anna Richert, *WWF SE*
Gun Rudquist, *Stockholm University, Baltic Sea Center*
Erik Sindhöj, *Research Institute of Sweden (RISE)*
Hanna Skoog, *Ax Foundation*
Vera Söderberg, *HKScan Oyj*
Anu Suono, *WWF SE*
Camilla Välimaa, *WWF SE*
Sara Vikman, *Lantmännen*
Peter Wiwen-Nilsson, *Race For The Baltic*

METABOLIC

+31 (0) 203690977
info@metabolic.nl
www.metabolic.nl

Meteorenweg 280M
1035RN Amsterdam
The Netherlands