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CiNURGi

Market Evaluation and Review of Policy Affecting Nutrient Recycling

October 2025

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RISE Research Institutes of Sweden

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Organisations from the following countries cooperate together to make that happen: Sweden (LP), Denmark, Estonia, Finland, Germany, Latvia, Lithuania and Poland.

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Foreword

CiNURGi (Circular Nutrients for a Sustainable Baltic Sea Region) is an Interreg BSR Core Project dedicated to advancing circular economy for nutrients within the Baltic Sea Region. By enhancing infrastructure, technology, and policy the project seeks to improve nutrient recovery from biomass and resource streams originating from agricultural, municipal, and industrial sources. This endeavor aligns with several regional and European strategies, including the HELCOM Baltic Sea Regional Nutrient Recycling Strategy, the EU's Circular Economy Action Plan under the Green Deal, and the Integrated Nutrient Management Action Plan of the Farm to Fork Strategy. The CiNURGi is ongoing from November 2023 to October 2027.

This report pertains to Task A1.3, focusing on a market evaluation and review of policies affecting nutrient recycling, taking the basis in already established or prospective value chains of best practices and most innovative solutions, in some cases also considering value chains in their later stages of development towards market readiness. The findings and activities detailed herein contribute directly to CiNURGi's overarching goals by featuring some best practices and most innovative solutions for recycling of nutrients in organic wastes, while at the same time presenting analyses of details of issues that must be considered for unlocking the potentials for nutrient recycling in the BSR region.

We acknowledge the collaborative efforts of our consortium, comprising 24 partners and 13 associated organisations from Denmark, Estonia, Finland, Germany, Poland, Latvia, Lithuania, and Sweden. Their dedication and expertise are instrumental in driving the project's success.

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

October 2025

Erik Sindhöj & Cheryl Cordeiro, CiNURGi Project Coordinators

RISE – Research Institutes of Sweden

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List of abbreviations

BAT	Best Available Technology
BBFs	Bio-based fertilizers
BEP	Best Environmental Practice
BSAP	Baltic Sea Action Plan
BSR	Baltic Sea Region
CAP	Common Agricultural Policy
CE	Circular Economy
CiNURGi	Circular Nutrients for a Sustainable Baltic Sea Region project
CRCF	Carbon Removals and Carbon Farming Certification
DERI	Direct Emission Reduction Impact
DM	Dry Matter
EC	European Commission
EoW	End-of-Waste
ESPP	European Sustainable Phosphorus Platform
ETS	Emissions Trade System
EU	European Union
FPR	Fertilising Products Regulation
GHG	Greenhouse Gases
GSC	Guiding Social Cost
GWh	Giga Watt hour
HELCOM	Helsinki Commission
MBM	Meat and Bone Meal
MPAs	Marine Protected Areas
N	Nitrogen
NA	Not Applicable
NGOs	Non-Governmental Organisations
NPK	Nitrogen, Phosphorus and Potassium
NRI	Nutrient Recycling Impact
OM	Organic Matter
P	Phosphorus
P_2O_5	Phosphorus Pentoxide
PE	Person Equivalents

RED	Renewable Energy Directive
RISE	Research Institutes of Sweden
SDGs	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TIS	Technological Innovation System
TRL	Technology Readiness Level
UK	United Kingdom
UN	United Nations
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
WG	Working Group
WWTP	Wastewater treatment plant

Executive summary

11 prospective value chains for recycling nutrients in organic wastes from farming, municipalities and industries were identified and analysed for their environmental, climate and social cost impacts as described in a parallel report (Foged et al., 2025) from the CiNURGi project.

This technical report contains analyses of end-user acceptance, market potentials and policy issues of bio-based fertiliser production in general, and specifically for the 11 mentioned value chains.

Farmer acceptance is pivotal for BBF market penetration. Surveys and interviews indicate a clear preference for BBFs that do not originate from wastewater, has a high plant availability of N and P nutrients, has a high nutrient content, particularly nitrogen, and can be field-spread and handled with conventional equipment. Farmers also see the fact that most BBFs contain organic matter as beneficial for improving soil structure fertility, which are critical factors for sustainable crop production. However, an overall criterion for crop farmers fertiliser preference is the price, which hampering the BBF market development since it is constrained by high production costs and the need for significant investments.

Market potential assessments considered resource availability, operational costs, potential revenues, and certification possibilities, including eligibility for organic farming. While organic waste availability suggests high market potential, national policies strongly influence feasibility. For example, mandates for sludge incineration and restrictions in organic farming can boost BBF use.

Policy analyses identified six key barriers and five incentives affecting BBF market development. Barriers include insufficient prioritisation of nutrient recycling under the Common Agricultural Policy (CAP) at Member State level. Incentives stem from broader EU initiatives, such as the European Green Deal and the Circular Economy Action Plan, which promote nutrient loss reduction and recycling. However, regulatory barriers often hinder the available incentives.

In conclusion, while the production of BBFs in general offers a promising avenue for sustainable nutrient management, realising their full potential necessitates concerted efforts to address economic constraints, develop fertiliser types that meets farmers demands, align regulatory frameworks, and support market development through targeted policies and stakeholder engagement. While social costs for producing BBFs are higher than comparable prices for nutrients in mineral fertilisers, crop farmers have some reservations towards BBFs due to their technical qualities and are generally unwilling to pay the same for nutrients in BBFs as for nutrients in mineral fertilisers.

Keywords: bio-based fertilisers (BBFs), nutrient recycling, Baltic Sea eutrophication, circular economy, nutrient management.

1. Introduction

The CiNURGi project aims at supporting the development towards a circular economy for nutrients in the Baltic Sea Region, by promoting the conversion of nutrient-containing organic waste from agriculture, municipals and industries into bio-based fertilisers (BBFs). This initiative supports sustainable nutrient management while reducing environmental impacts of nutrient loss, particularly eutrophication.

A parallel CiNURGi report (Foged et al, 2025) explains how value chains for BBF production were identified and initially prioritised for being longlisted for further analyses, and it also presents the method for analysing them for their environmental, climate and economic performance, as well as the results of these analyses.

The 11 longlisted value chains, comprising collection of nutrient-containing organic wastes, their processing into BBFs and distribution to end users, are presented in the mentioned, parallel report, and for clarity and ease repeated in Table 1, since these are subject of further analyses in this report.

Table 1: Longlisted value chains, the title and the value chain code. Listed in an accidental order.

Main value chain owner	Title of longlisted value chains	Value chain code*
AquaGreen	Piloting dewatered sewage sludge to biochar through drying and pyrolysis	MTS1
Bio10	From digestate to separation liquids and solids via separation	MML
BioCover	From raw to acidified slurry via in-field acidification	FCL
BioPir	From digestate to separation solids and liquids via settling and separation	FMS
EasyMining - Aqua2N	Piloting sludge reject water to ammonium sulphate solution through chemical fixation	MCL
Not specified	Validating dewatered sewage sludge to P-rich end-product via drying, mono-incineration and chemical extraction	MTS2
EkoBalans	Piloting digestate to organic fertiliser pellets through separation, drying and pelletising	FMP1
Gyllebo	From meat and bone meal to fertiliser pellet though mixing and pelletising	IMP
Planteo	From digestate to organic fertiliser pellets via separation, drying and pelletising	FMP2
Sanitation360	Testing urine to fertiliser granules through source separation, chemical fixation and drying	MCG
Soepenberg	Prototyping activated sludge to struvite fertiliser through chemical processing	MCS

** The value chain code comprise a letter for the waste sector (F = Farming, M = Municipal, I = Industry), a letter for the main processing method (M = Mechanical, C = Chemical, B = Biological, T = Thermal), and a* *letter for the physical form of the resulting bio-based fertiliser (L = Liquids, P = Pellets, G = Granules, and S= Other solids).*

1.1. Scope of this study

This study is further analysing some important aspects of the 11 longlisted value chains in Table 1, namely end-user acceptance of the resulting bio-based fertilisers, the market potentials for the value chains, and relevant policy considerations evaluated through a SWOT-based analysis.

1.2. Objective of this technical report

This technical report performs a market evaluation and a review of policies affecting nutrient recycling. Aiming at identifying BBFs that from all perspectives shows the greatest potential for increasing nutrient recycling in the Baltic Sea Region (BSR), a final ranking / shortlisting of six out of 11 longlisted value chains that are already evaluated for their social costs will be done by combining this with further assessments of end-user perceptions, market potentials and policy considerations.

2. Considerations of end-user perceptions

This chapter presents an overview of farmers' perceptions regarding the identified value chains for bio-based fertilisers (BBFs). It begins with a review of three key studies exploring farmers' attitudes towards BBFs in Sweden, Denmark and Finland, followed by a summary of general insights gathered during CiNURGi events and stakeholder's dialogues. Finally, each value chain was evaluated and scored by the project expert group, drawing on both the literature and stakeholder feedback to assess end-user acceptance.

2.1. Main findings from the studies on farmers' perspectives

SWEDEN

A recent study by Lima et al. (2024) surveyed a representative sample of Swedish farmers to explore their perceptions on BBFs, focusing on both potential benefits and challenges. The findings show a strong interest among Swedish farmers in BBFs, particularly due to their positive effects on soil health. Farmers emphasized the value of organic matter content in BBFs for improving soil structure and long-term fertility, critical factors for sustainable crop production.

Farmers expressed broad openness towards BBFs from diverse origins and in various forms. There was a notable preference for digestate-based fertilisers, including both solid and liquid forms, suggesting a willingness to adapt diverse BBF products tailored to specific farm conditions and soil needs. However, significant concerns were also raised. A primary concern was the risk of soil compaction due to heavy loads when applying wet and bulky materials with high water content and low nutrient concentrations. As a result, farmers indicated a preference for pelletised or granular BBFs, which are easier to handle and reduce soil compaction risks.

The survey also revealed that sustainability and circular economy considerations are increasingly important among Swedish farmers. Many expressed a desire to expand BBF use, particularly among those with limited prior experience. However, the willingness to adopt remains highly sensitive to price dynamics relative to mineral fertilisers. Lima et al. (2024) therefore recommend policy incentives to stimulate broader adoption and promote greater nutrient circularity.

DENMARK

Similarly, Case et al. (2017) found that soil improvement was a key motivator for farmers adopting BBFs among Danish farmers. While concerns about soil compaction existed, respondents reported an overall positive impact on soil structure where appropriate application practices were followed.

Farmers viewed BBFs as cost-effective and accessible, especially on livestock farms where raw materials are readily available. Nonetheless, several barriers to BBF adoption were identified, including odour nuisances from minimally processed manures, inconsistent nutrient content complicating fertilisation planning, limited availability of processed BBFs, high equipment costs, and challenges integrating BBRs into existing farm operations. As in Sweden, financial support mechanisms and investments in spreading technologies were proposed as critical enablers.

FINLAND

A study by Myllyviita and Rintamäki (2018) surveyed Finnish farmers' perceptions on BBFs. Over 70% of farmers considered BBFs a valuable supplement to mineral fertilisation practices. However, more than 60% felt that BBFs alone were not sufficient to achieve their desired fertilisation levels. Farmers recognised benefits such as improved soil quality, increased growth potential and a positive impact on yield potential.

Organic farmers showed significantly more positive attitudes toward BBFs than conventional ones. Over 65% of organic farmers preferred BBFs to mineral fertiliser, versus only 37% of conventional farmers. Despite general acceptance, there was a strong scepticism towards BBFs derived from human or industrial waste, particularly among organic farmers, while by-products from the food industry were viewed more favourable.

Farmers emphasised the importance of BBFs being transportable, storable, contain readily available nutrients, low-cost, and have optimised nutrient ratios for different cropping systems. Storage and application challenges were common, with 65% of cereal farmers and 55% of livestock farmers reporting difficulties storing BBFs on their farms. Granular products were rated highest in terms of preference, followed by dry solid fraction products; liquids and pelletised forms were considered less suitable by many respondents.

Cooperation between farmers and fertiliser producers was widely seen as essential to improving adoption. Support mechanisms identified as critical for improving BBF adoption included agricultural advisory services, hands-on training, and financial subsidies to cover additional costs or investments.

Synthesis of Key Findings

Together, these studies present a consistent picture of farmer perspectives across the Nordic region. Farmers recognise the environmental and soil health benefits of BBFs, but emphasise the need for:

- Easier handling and application (e.g., granules or pellets preferred)
- Consistent nutrient quality
- Competitive pricing relative to mineral fertilisers
- Financial incentives and technical support
- Clear guidance and collaboration between fertiliser producers and farmers.

Ongoing support from policy makers, researchers, and the private sector will be crucial to unlock the full potential of BBFs in mainstream agricultural practices.

2.2. Main findings of CiNURGi's stakeholder events

2.2.1. Denmark

In January 2025, Energibyen Skive presented the CiNURGi project at two major agricultural events in Denmark: the national Plant Congress (Picture 1) and the regional Fjordland Congress (Picture). The Plant Congress is Denmark's leading annual forum for farmers, agricultural researchers, industry, organisations and policymakers. The 2025 event, attended by approximately 1,800 participants, focused on regenerative agriculture and strategies to build soil health and resilience. The Fjordland Congress, organized by the regional agricultural advisory group Fjordland, brought together around 230 participants from Central and Western Jutland. The 2025 event focused on Denmark's new "Agreement on a green Denmark" (Regeringen, 2024), aiming to restructure land use to improve water quality, biodiversity, and climate resilience.

Picture 1: CiNURGi is presented by Energibyen Skive at the national Plant Congress and contacts are made with stakeholders.

2.2.1.1. Fertiliser compatibility with existing farm machinery

In discussions with farmers at both events, a key priority emerged: new fertilisers must be compatible with existing machinery to avoid costly investments in new equipment. Farmers stressed the importance of transparency in nutrient content, particularly regarding P and N. While exact P/N ratios were not expected to be consistent across all deliveries, farmers requested precise nutrient specifications per bulk bag to enable accurate fertilisation planning.

Additionally, farmers noted the growing importance of traceability regarding the biomass origin used in fertiliser production, anticipating that sustainability certifications and origin disclosure could become increasingly important factors in purchase decisions.

2.2.1.2. Farmer interest and concerns regarding biochar

Biochar as a soil amendment generated considerable interest among farmers, especially for its potential benefits in soil health improvement and carbon retention. However, enthusiasm was accompanied by caution, regarding the feedstock origin. Biochar derived from agricultural residues was generally well-received, while biochar produced from sewage sludge faced scepticism due to concerns about contaminants and regulatory uncertainties. Overall, farmers expressed a willingness to adopt biochar, provided that clear guarantees about quality, safety and origin could be demonstrated.

Picture 2: EnergiByen Skive presented CiNURGi at the Fjordland Congress and discussed with farmers about their experiences and expectations with recycled fertilisers.

2.2.1.3. Anticipated regulatory changes and farmer expectations

Farmers showed strong awareness of upcoming regulations affecting nitrogen fertiliser use, set to take effect in 2027. The new regulations aim to reduce nitrogen leaching into sensitive aquatic ecosystems, notably the Limfjord near Skive. A targeted approach will introduce stricter controls on nitrogen application in the vulnerable areas to mitigate nutrient loss and protect water quality. Farmers indicated a need for early guidance, advisory support, and transitional measures to adapt to these changes without undue economic disruption.

2.2.2. Finland: Agri-Environmental Knowledge Exchange Workshop

A dedicated CiNURGi workshop (Picture 3) was held as part of the Agri-Environmental Knowledge Exchange Conference in Turku, Finland, on 13–14 November 2024. On 13 November, CiNURGi's Finnish partners, in collaboration with the Finnish Programme for Nutrient Recycling (Ministry of Agriculture and Forestry of Finland), organised this workshop which focused on two key themes:

1) Quality requirements for BBFs, and
2) Market development – with the first theme discussed in this section.

The workshop welcomed 32 participants, including representatives from farmers and their organisations, SMEs, public authorities, NGOs and research institutes, ensuring a broad stakeholder dialogue. In parallel, CiNURGi also hosted a networking stand at the conference, providing further opportunities for engagement with partners and stakeholders.

Key findings on BBF quality and implications for end-user acceptance and public perception included:

- **Consistency and reliability**: BBFs must meet clearly defined quality standards that align with product descriptions and labelling.
- **Nutrient specification**: The plant-available nutrient content should be well-characterised, including residual fertiliser effects over multiple growing seasons and across different soil types.
- **Contaminant-free products**: BBFs must be free from physical impurities (e.g., plastics, glass), heavy metals, pesticides, and antibiotics. Ensuring hygienic quality is essential for both safety and acceptance.
- **Preventing plastic pollution**: Emphasis was placed on eliminating contamination at the source, especially from so-called "biodegradable" plastics that do not fully degrade during processing.
- **Market standards surpass legal requirements**: In many cases, market demands (e.g. from grain buyers) are stricter than current regulations, highlighting the need for producers to exceed minimum legal thresholds.
- **Production chain transparency**: There is a clear need for traceability and transparency throughout the BBF production process.
- **Operator knowledge**: Biogas and anaerobic digestion (AD) plant operators must monitor input materials and nutrient profiles, despite seasonal variability in feedstocks.
- **Environmental labelling**: Introducing labelling schemes (comparable to organic or fairtrade labels) for BBFs and food grown with them could enhance consumer trust and acceptance.

Additional challenges identified:

Participants also highlighted several broader barriers affecting BBF adoption:

  - **Low nutrient concentrations**, particularly low N levels in BBFs can reduce fertiliser effectiveness and market competitiveness.
  - **Logistical barriers** such as high transport, storage, handling, and application costs, along with labour requirements can discourage adoption
  - **Infrastructure limitations** on many arable farms, such as insufficient storage capacity or equipment, though subcontracting may offer a partial solution.

These insights underline the importance of addressing quality assurance, transparency, and logistics to support greater adoption of BBFs by farmers and wider acceptance by markets and the public.

Picture 3: Final summary of the CiNURGi workshop on 13 November 2024 in Turku, Finland.

2.2.3. Sweden

2.2.3.1. Stakeholder engagement at Borgeby Field Days 2024

Borgeby Field Days is Sweden's largest agricultural fair, drawing farmers, advisors, researchers, and industry representatives from across Northern Europe. The 2024 event, held on 26-27 June, focused on the theme "Agriculture of the Future" and highlighted developments in autonomous machines, precision farming tools, and AI models integrated into farm management systems. It attracted 19,900 visitors and featured 415 exhibiting companies.

At Borgeby 2024, CiNURGi operated a dedicated tent (Picture 4 and 5), showcasing the role of BBFs in promoting circular nutrient management. The project aimed to raise awareness about BBFs derived from organic wastes and to identify barriers and opportunities for their adoption in Swedish agriculture.

Picture 4: CiNURGi's tent at Borgeby Field Days.

A key component of CiNURGi's participation was a stakeholder survey targeting farmers, agricultural advisors, and students. The survey assessed acceptance levels, concerns, and factors influencing adoption of BBFs.

Picture 5: CiNURGi's team at the tent at Borgeby Field Days 2024.

The survey revealed that many farmers are already using BBFs such as digestates, biochar and blood meal. However, conventional mineral fertilisers remain dominant, primarily due to their predictability, nutrient consistency, and ease of use. Despite this, there was strong interest in adopting BBFs, particularly for products like

- Pellets (N:P:K 8:1.5:0.3) from EkoBalans,
- Dried digestate solids (N:P:K 1.5:1.5:1) from More Biogas,
- Biochar (N:P:K 1:5:3.4) from digestate solids from More Biogas

These products and more were showcased at the fair (Picture).

However, several concerns were raised:

- **Nutrient performance**: Farmers expressed doubts about the consistency and timing of nutrient release compared to conventional mineral fertilisers.
- **Application and Handling Challenges**: Spreading techniques, storage needs, odour management, and logistical complexity were noted as barriers.
- **Regulatory and Certification Uncertainty**: There were concerns about BBF compliance with Swedish and EU fertiliser regulations and eligibility for organic farming certification.
- **Economic factors**: The cost competitiveness of BBFs versus mineral fertilisers emerged as a critical factor. Many farmers indicating that financial incentives, such as subsidies or market premiums for sustainable farming, could encourage a broader shift toward BBFs.

Picture 6: Products showcased at Borgeby Field Days 2024.

2.2.3.2. Key insights and implications for BBF adoption

The results from Borgeby Field Days 2024 indicate growing interest in BBFs but also highlight significant barriers to large-scale adoption.

To facilitate wider use of BBFs in Sweden, the following measures were identified as critical:

- **Improving product formulations**: Enhancing
- nutrient availability, consistency, and performance.
- **Clarifying Regulatory Frameworks**: Providing clear guidance on certification and compliance for BBFs.
- **Expanding economic incentives**: Introducing subsidies or market-based incentives to improve BBR competitiveness.
- **Demonstration Projects and Outreach**: Promoting farmer-led trials and demonstrations to showcase BBF performance under real farming conditions.

The findings align with the broader research, including Lima et al. (2024), which also identified price sensitivity, uncertain over nutrient release, and practical challenges as key barriers for BBF adoption.

Together, the Borgeby event results and Lima et al.'s study reinforces the need for tailored policy support, improved product quality, and strategic market development to drive the transition toward sustainable nutrient recycling in agriculture.

2.3. End-user perceptions on CiNURGi's longlisted cases

Table presents an overview of end-user perceptions for the 11 longlisted value chains (as referenced in Table 2), based on insights from the reviewed literature and key findings from CiNURGi stakeholder events. The assessment focused on general farmer attitudes towards different BBF characteristics – such as bulk solids, liquids, pellets, and other formats – rather than focusing on specific products or company names.

To facilitate a comparative ranking, each perception indicator was scored as either positive (+) or negative (-). The individual scores were then summed to provide an indicative acceptance ranking for each value chain. However, it is important to note that the scoring was conducted by the expert working group and therefore should be interpreted as such. While it drew on stakeholder dialogues and literature findings, they might not fully capture the diversity of views among farmers.

Table 7: Key aspects of farmer perceptions and acceptance for BBF products.

Case	Score	End-user perceptions		
		Raw material and process	Product quality	Product use
IMP	+8	Products based on animal by-products such as meat and bone meal are well accepted (+) Drying and pelletising well received (+) Nutrient content is adjusted with mineral products that are allowed in organic farming, and other components, such as vinasse (+)	Nutrient content comparable to mineral fertilisers (+)	Profitable to transport (+) Easy to store on farms (+) Pelleted products can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)
MCG	+4	Scepticism towards human and sewage sludge derived products (-)	Nutrient content comparable to mineral fertilisers (+)	Profitable to transport (+) Easy to store on farms (+) Product can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)
MCS	+4	Scepticism towards sewage sludge derived products (-)	Nutrient content comparable to mineral fertilisers (+)	Profitable to transport (+) Easy to store on farms (+) Product can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)
MTS1	+3	Scepticism towards sewage sludge derived products (-) Process eliminates risk of organic contaminants, pathogens and microplastics (+)	P content comparable to mineral fertilisers (+) In current processing, decreased P availability	Profitable to transport (+) Easy to store on farms (+)

Case	Score	End-user perceptions Raw material and process	Product quality	Product use
		N in the sewage sludge is lost (-)	to plants (-) High carbon content (+)	Product needs to be developed to facilitate spreading with existing machinery (+/-) No high risk of soil compaction (+)
FCL	+1	Manure based products well accepted (+) No observations on slurry acidification (NA)	Reduced loss of N from the slurry compared to raw slurry manure (+) Simultaneous S fertilisation (+)	Heavy machinery needed, risk of soil compaction (-) For crop farms, need for specific application equipment / contractor (-)
MTS2	+2	Scepticism towards sewage sludge derived products (-) Process eliminates risk of organic contaminants, pathogens and microplastics (+) Carbon in the sewage sludge is lost (-) N in the sewage sludge is lost (-)	P content comparable to mineral fertilisers (+) Decreased P availability to plants (-)	Profitable to transport (+) Easy to store on farms (+) Product can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)
FMS	+1	Manure based products well accepted (+) Settling and screw separation of the bottom fraction of digestate accumulates P that can be separated into solids and transported where required (+)	Solids high in organic matter (+) High P content of solids (+) Liquids low in nutrients (-)	Dry solids profitable to transport (+) Heavy machinery needed, risk of soil compaction (-) Bulk products (liquid and solid) difficult to store at crop farms (-) For crop farms, need for specific application equipment / contractor (-)
MML	-1	Products based on digestate of municipal wastes excluding wastewaters and food industry side steams are well accepted (+)	Solids high in organic matter (+) Nutrient content may vary depending on seasonal variation of feedstocks (-)	Dry solids profitable to transport (+) Heavy machinery needed for liquids, risk of soil compaction (-) Bulk products (liquid and solid) difficult to store at crop farms (-)

Case	Score	End-user perceptions Raw material and process	Product quality	Product use
				For crop farms, need for specific application equipment / contractor (-)
MCL	-2	Scepticism towards sewage sludge derived products (-)	High N content of the product (+) Simultaneous S fertilisation (+)	Bulk products (liquid) difficult to store at crop farms (-) Possible soil compaction risk while applied to soil (-) For crop farms, need for specific application equipment / contractor (-)
FMP1	+7	Products based on digestate of liquid pig manure, municipal food waste, slaughterhouse waste and other food industry byproducts are well accepted (+) Drying and pelletising well received (+) Polymer additive can reduce acceptability. Not allowed in organic farming (-)	High organic matter content (+) Nutrient content comparable to mineral fertilisers (+)	Profitable to transport (+) Easy to store on farms (+) Pelleted products can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)
FMP2	+5	Products based on digestate of agricultural and food waste (100% plant-based) are well accepted (+) Drying and pelletising well received (+) N is partly lost in drying (-)	High organic matter content (+) Rather low nutrient content (-)	Profitable to transport (+) Easy to store on farms (+) Pelleted products can be used in crop farms with existing machinery (+) No high risk of soil compaction (+)

Note: Based on literature review and general findings from CiNURGi events.

2.4. Summary/conclusions on end-user perceptions

A total of 11 different value chains were evaluated based on end-user perceptions gathered through national studies and CiNURGi stakeholder events. The analysis revealed that BBFs derived from manure, animal by-products (e.g., meat and bone meal), and digestates from municipal waste (excluding wastewater) and industrial food residues are generally well accepted by farmers. In contrast, there is greater scepticism toward products derived from sewage sludge, largely due to concerns over contaminants and traceability.

In terms of product quality, farmers prefer BBFs with high nutrient content, particularly with good plant availability of N and P, comparable to mineral fertilisers. A high organic matter content was also viewed positively, due to its role in improving soil structure and long-term fertility. Conversely, BBFs with low nutrient concentration or poor nutrient availability were seen as less attractive and less viable for practical use.

Regarding product format and usability, pelleted and granulated BBFs were consistently favoured for their ease of store, efficient transport, and compatibility with existing farm machinery, particularly on arable farms. These formats also reduce the risk of soil compaction. In contrast, liquid BBFs were perceived as more difficult to manage, especially on crop farms, due to the need for specialised application equipment, limited on-farm storage, and the potential for soil compaction from heavy machinery.

Overall, the findings underscore the importance of developing high-quality, concentrated, and easy-to-use BBF products to meet farmer needs and expectations. Addressing concerns around product quality, traceability, and practical usability will be critical for increasing end-user acceptance and supporting the wider adoption of nutrient recycling solutions in agriculture.

3. Considerations on market potential

The market potential of the 11 longlisted value chains was assessed through a multi-criteria evaluation, considering both economic viability and broader feasibility indicators. In addition to identifying sound business models, the aim was to highlight opportunities for further development and pinpoint value chains requiring. This assessment methodology draws on decision-support frameworks and multi-criteria analysis concepts, as described in the literature (Chrispim et al., 2020; Ulinder et al., 2025).

The evaluation process involved defining relevant criteria, collecting data for each value chain, assigning scores, and applying weighted rankings based on stakeholder input.

Evaluation criteria

The criteria used to evaluate market potential included:

- **Expected costs and savings** compared to the baseline.
- **Technology Readiness Level (TRL)**.
- **N and P recovery potential**, estimated from available raw material volumes in the Baltic Sea Region and assumed process losses.
- **Human resource requirements** (skills and labour).
- **Scalability and flexibility** of implementation.
- **Incentive for adoption**, including alignment with policy goals or market trends.
- **Certification or Quality Assurance Status** of the final BBF product.

Scoring methodology

Each value chain was scored for every criterion as

- +1 (favourable)
- 0 (neutral)
- –1 (unfavourable)

Scores were assigned relative to the comparative performance of the longlisted value chains (except for costs and revenues indicators, which were benchmarked against each case's specific baseline scenario). This relative scoring approach allowed for clearer differentiation of strengths and weaknesses across the value chain. A weighting system was applied to reflect the perceived importance of each criterion. Weighting was determined through a poll conducted among the project expert group, where participants ranked the criteria in order of importance. Based on their ranking, weights of 3 (highest importance), 2 (medium importance), and 1 (lowest importance) were assigned.

Weighted scores were calculated by multiplying each criterion score by its corresponding weight. Summed weighted scores were then used to produce the final comparative ranking of the value chains.

Data sources and estimations of nutrient recovery

The assessment combined data from technology providers, literature sources, and prior experience within the expert group constellation.

To estimate the nutrient recovery potential, descriptions of raw material sources were analysed alongside provider-supplied data on N and P retention through processing. These inputs enabled calculation of total N and P content in the final production (see Annex 1), allowing a comparative view of each value chain's nutrient recycling performance relative to baseline waste management scenarios.

Full scoring results, including weighted ranking, are presented in section 3.3.

3.1. Raw materials – availability, current agricultural use and future developments

The raw materials considered in the evaluated value chains include a range of organic waste streams from municipal, agricultural and industrial sources. They were categorised as follows:

Municipal

- Dewatered sewage sludge (MTS1)
- Ash from sludge incineration (MTS2)
- Reject water from sludge dewatering (MCL)
- Excess activated sewage sludge (MCS)
- Source-separated urine (MCG)

Agriculture

- Animal slurry (FCL)

Industry

- Meat and bone meal (IMP)

Cross-Sectoral Materials (Combinations of Agriculture, Municipal and Industrial streams):

- Digestate from co-digestion plants (manure, municipal food waste and industry waste digested together (MML/ FMS/ FMP2 / FMP1)

Each raw material is further described below. (Note: all digestate-based raw materials are discussed collectively under a common section).

3.1.1. Dewatered sewage sludge

3.1.1.1. Amounts

The total annual sewage sludge production in the Baltic Sea countries, excluding Russia, is estimated at approximately 2.9 million tonnes, measured in dry mass (DM) (Eurostat, 2020). Sewage sludge is a by-product of gravimetric, chemical, and biological treatment processes at wastewater treatment plants (WWTPs). Its composition varies depending on the specific treatment configuration employed.

After separation from the wastewater stream, raw sludge typically contains only a few of percent DM. It is subsequently thickened and dewatered, with the resulting liquid phase typically returned to the treatment process. The final sludge product usually leaves the WWTP in dewatered form, i.e., with a moisture content of around 70-80%. The distribution of dewatered DM by country is shown in Figure 1.

Based on the total dry mass and typical nutrient concentrations, 2-6% N and up to 6.6% P (0.1-15.2% when expressed as P_2O_5) in relation to DM (Kominko et al., 2024). The estimated annual nutrient amounts in sewage sludge are approximately 120,000 t N and 96,000 t P[1].

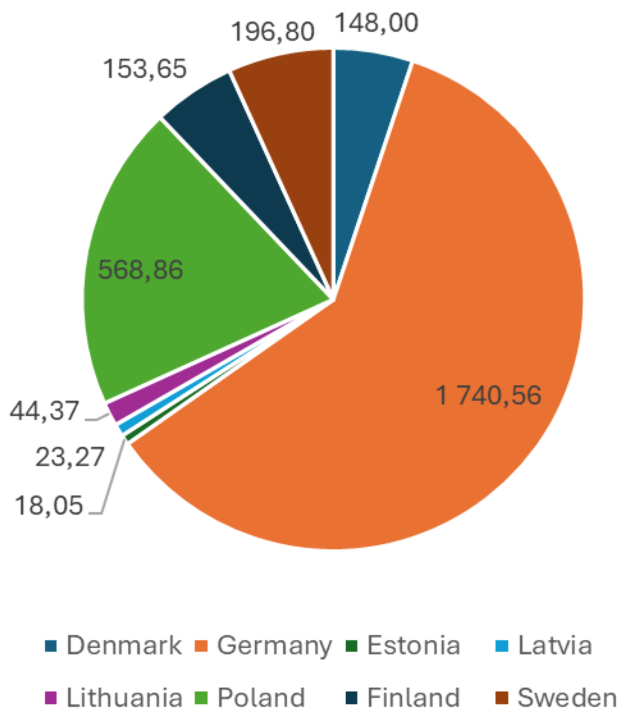

Figure 1: Amounts of wastewater sludge generated in the countries around the Baltic Sea (excluding Russia) (thousand ton, counted as dry mass). Source: EUROSTAT, 2020.

3.1.1.2. Agricultural use

According to Eurostat data from 2020, approximately 51% of sewage sludge in the Baltic Sea Region (excluding Russia) was incinerated, while 23% was used in agriculture. However, sludge management practices vary widely among countries, as shown in Figure 1. The category "other use" is notably large in Latvia and Poland, although its specific destination is not clearly defined in the Eurostat metadata. National sources, such as Statistics Poland (2022), indicate that about 44% of industrial and municipal sludge in Poland undergoes thermal treatment, suggesting that Eurostat's "other use" category may include non-incineration thermal processing methods. (Statistics Poland, Spatial and Environmental Surveys Department, 2022).

[1] The similar estimate of Task A1.1 is slightly lower, 111,000 t N and 75,000 t P.

Agricultural use is the predominant sludge destination in Demark, Estonia and Sweden, whereas incineration clearly dominants in Germany. In Finland, sludge is primarily used through composting and other applications[2]. Lithuania reported a relatively balanced distribution among incineration, composting (and other applications), and agricultural use.

Interpretation of sludge use data is complicated by differences in national reporting methods. For example, the Danish Environmental Agency (Miljøstyrelsen) reported that only 2% of sludge was incinerated in 2020, while the Danish Competition and Consumer Agency (Konkurrence- og forbrugerstyrelsen) provided significantly higher figures more consistent with the Eurostat's estimates (Danish EPA, 2024). Similarly, discrepancies exist in Swedish data. Statistics Sweden (2022a) reported that "annan användning" (other use) accounted for only 6% of sludge application in 2020, while Eurostat reported 24% (see Figure 2). These discrepancies between Eurostat and national datasets highlight the challenges in developing a consistent understanding of sludge management practices across the Baltic Sea Region.

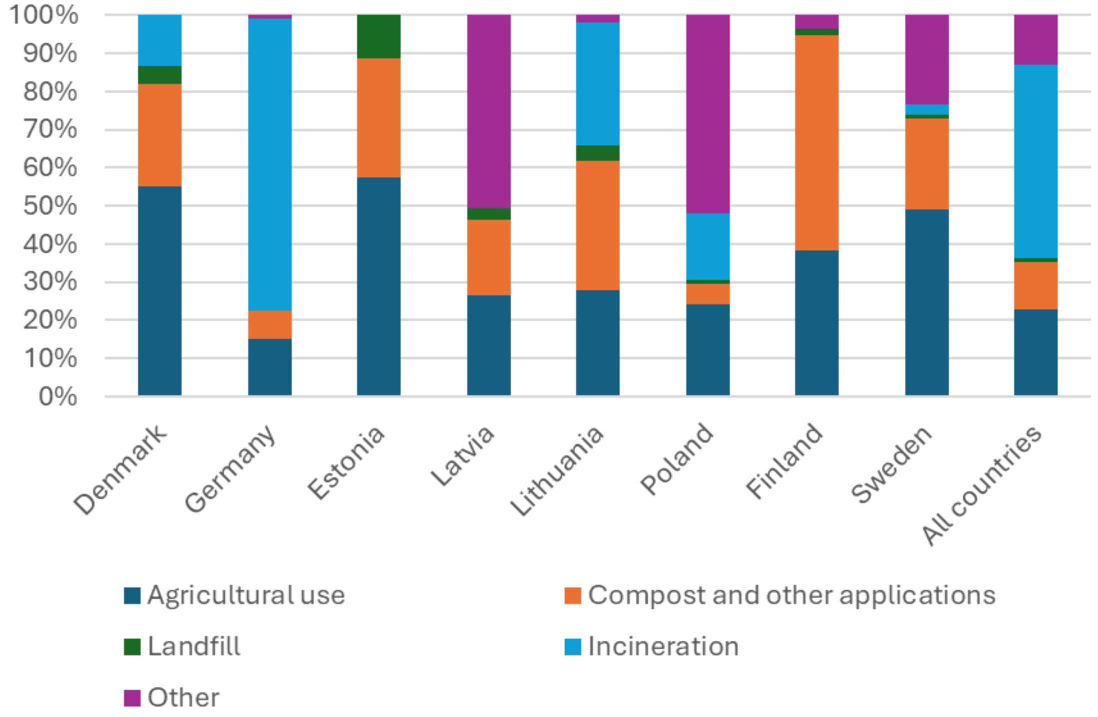

Figure 2: Type of sludge disposal in the countries around the Baltic Sea (excluding Russia) (% in each disposal category)

3.1.1.3. Future development of raw material availability

The ongoing expansion of centralised wastewater treatment systems is expected to increase the volume of collected wastewater and, consequently, the amount of generated sludge in the

[2] These Eurostat categories are not entirely clear, and some of the composted are likely used in agriculture. This is the case at least in Finland that sludge composts are also partly directed to agriculture. In 2023 Approximately 82% of the sludge was digested. Of all WWT sludge, 50% is used in agriculture according to this report: https://www.vesilaitosyhdistys.fi/site/assets/files/10041/yhdyskuntalietteen_kasittelyn_ja_hyodyntamisen_nykytilannekatsaus_2025.pdf (only in Finnish)

coming years. In response to this trend, the policy landscape across EU member states may become harmonised following upcoming revisions to the European Sludge Directive.

In parallel, the updated Urban Wastewater Treatment Directive (UWWTD), adopted in 2024, introduces new mandatory nutrient recovery targets. Specifically, P reuse will become mandatory starting in 2027, with requirements for N reuse expected to follow in future regulatory updates. These regulatory changes are likely to have a significant impact on national strategies for sludge management and nutrient recycling. They ae expected to accelerate the deployment of advanced recovery technologies, enhancing the availability of recovered raw materials for BBF production across the Baltic Sea Region.

3.1.2. Ashes from incineration of sludge

3.1.2.1. Amounts

Approximately 51% of sewage sludge generated in the Baltic Sea Region is incinerated, largely due to the high incineration rates in Germany. Assuming an average ash content of 36% of the sludge’s DM (Chang et al., 2022), this corresponds to an estimated 530,000 ton of sludge ash produced annually in the region.

During incineration, nearly all N is lost through volatilisation, making the N content in the sludge ash negligible compared to other raw materials. In contrast, P and K is largely retained in the ash. The P content in sludge ash is similar in magnitude to that in dewatered sewage sludge, estimated at approximately 96,000 tonnes per year. This highlights the considerable potential for P recovery from sludge ash in the Baltic Sea Region. However, to fully exploit this potential, greater capacity for mono incineration of sludge (separate from other organic wastes) is needed. Mono-incineration produces ash with higher P concentrations, which is more suitable for subsequent P recovery.

3.1.2.2. Agricultural use

The direct use of sludge ash in agriculture remains uncommon across the Baltic Sea Region. The largest volumes of sludge ash are generated in Germany, where mono-incineration of sludge has become increasingly widespread. In 2020, approximately half of all sewage sludge in Germany underwent mono-incineration (Schnell et al., 2020), a trend driven by regulatory changes introduced in 2017.

Under these German regulations, WWTPs serving more than 50,000 person equivalents (PE) are prohibited from applying sewage sludge directly to land. At the same time, the law mandates P recovery from sludge. A transitional period is currently underway, with full implementation required by 2029 for large WWTPs and by 2032 for those serving between 50,000 and 100,000 PE.

At present, the most common practice in Germany is to dispose of mono incineration ash in landfills or as backfill material, while P recovery technologies are still being developed and scaled up for fertiliser production (Schnell et al., 2020).

3.1.2.3. Future development of raw material availability

An increase in the mono-incineration of sludge in Germany, driven by regulatory requirements limiting co-incineration with other waste streams (Schnell et al., 2020). This trend suggests that the volume of sludge ash suitable for P recovery will continue to grow over the coming years, enhancing the availability of raw materials for P recovery technologies and fertiliser production.

3.1.3. Reject water from sludge dewatering

3.1.3.1. Amounts

Reject water refers to the liquid fraction produced during the dewatering of sewage sludge. Based on the estimated volume of sludge DM in the Baltic Sea Region, and assuming a 25% DM content in dewatered sludge and 5% DM in thickened sludge prior to dewatering, the total volume of reject water generated annually in the region is estimated at approximately 46 million ton.

Using average nutrient concentrations of 0.53 kg N/tonne and 0.19 kg P/tonne of reject water (Högstrand et al., 2022), the annual nutrient load in reject water is estimated at

- 25,000 tonnes of N
- 8,800 tonnes of P

These figures highlight the significant nutrient flows contained in reject water and demonstrate its potential for targeted nutrient recovery from this often-overlooked stream.

3.1.3.2. Agricultural use

Direct application of reject water in agriculture is currently not practiced. Instead, reject water is typically recirculated back to the WWTP for further processing. Some facilities employ side-stream treatment processes to reduce N concentrations before recirculation. However, recovering N directly from reject water presents a promising opportunity. Targeted N recovery could yield recycled N fertilisers while simultaneously reducing the N load on WWTPs. This would lower energy consumption and greenhouse gas emissions associated with conventional N removal methods, such as nitrification and denitrification. As such, targeted nitrogen recovery from reject water could provide both environmental and operational benefits.

3.1.3.3. Future development of raw material availability

The expansion of centralised wastewater treatment systems is expected to continue increasing sewage sludge volumes across the Baltic Sea Region, leading to a corresponding rise in reject water and N generation. This trend further underscores the importance of developing efficient technologies and strategies for nutrient recovery from reject water streams to capture otherwise lost N and P resources.

3.1.4. Excess activated sewage sludge

3.1.4.1. Amounts

Excess activated sludge is produced during the biological treatment of wastewater, prior to thickening and dewatering. The total amount of excess activated sewage sludge generated annually in the Baltic Sea Region is estimated to approximately 240 million tonnes, based on an assumed DM content of 1.2% (Kulikova et al., 2022) and the total amount of DM reported in the previous section.

The nutrient content of excess activated sludge is estimated to around:

- 110,000 tonnes N
- 44,000 tonnes P

calculated based on 3.7 % N and 1.5 % P relative to DM (Kulikova et al., 2022). It should be noted that this estimation differs from the N and P content reported for dewatered sludge.

In principle, nutrient levels should be higher in excess activated sludge than in dewatered sludge, since part of P and N is lost to the reject water during the dewatering process. Nevertheless, the order of magnitude of these estimates seems reasonable for comparative purposes.

3.1.4.2. Agricultural use

Excess activated sewage sludge is not used in agriculture, primarily due to its very low DM content, which makes transport impractical. Typically, thickening and dewatering are carried out onsite at WWTPs. At smaller WWTPs, thickened sludge is sometimes transported to a larger WWTP for dewatering.

3.1.4.3. Future development of raw material availability

As centralised wastewater treatment infrastructure continues to expand across the Baltic Sea Region, the generation of excess activated sludge is also expected to increase. This trend mirrors the anticipated growth in dewatered sludge volumes, unless wastewater treatment processes are drastically changed.

3.1.5. Urine

3.1.5.1. Amounts

Figure 3 presents the estimated total annual human urine production in the Baltic Sea countries (excluding Russia), expressed in millions of litres. The estimates are based on average urine output of approximately 1.5 litres per person per day, equating to around 550 litres per person per year (Al-Kazwini and Simhadri, 2025). National urine production volumes were calculated by multiplying these figures by each country’s population (Eurostat, 2020).

The combined annual human urine production across the Baltic Sea region was estimated at approximately 46.5 billion litres (Figure 3). Using an average nutrient content of 12 g/L N and 0.5 g/L P (Pradhan, S. K. et al., 2019), this corresponds to an estimated annual nutrient load of:

- 980,000 tonnes of N
- 41,000 tonnes of P.

These figures highlight the clear significant nutrient recovery potential of source-separated human urine.

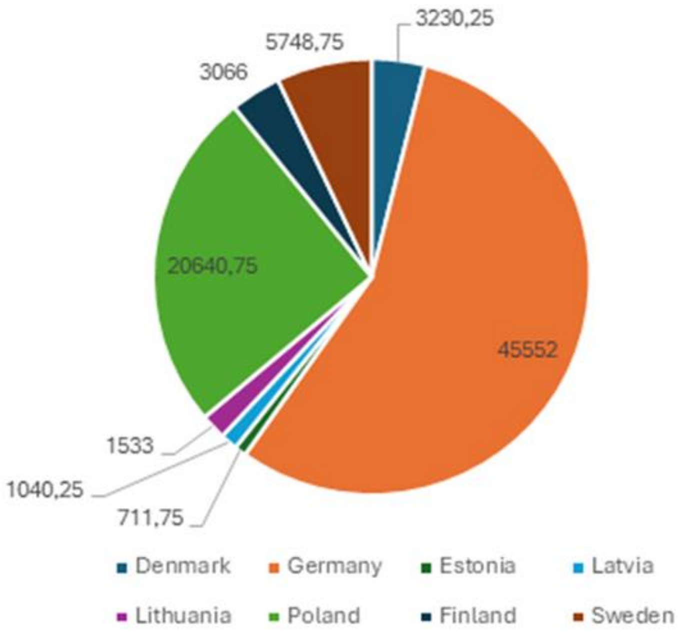

Figure 3: Amounts of urine production in the countries around the Baltic Sea (excluding Russia) (thousand tonnes, counted as dry mass). Source: Eurostat (2020).

3.1.5.2. Agricultural use

The use of human urine as fertiliser in agriculture across the Baltic Sea Region remains limited to a few pilot or demonstration cases. A key prerequisite for wider application is the implementation of source-separating sanitation systems that enable the separate collection and treatment of urine.

Currently, the technological innovation system supporting urine recycling remains underdeveloped, with limited infrastructure, regulatory frameworks, and operating knowledge (Aliahmad et al., 2022).

Despite these barriers, urine offers significant potential for nutrient recovery. Although it represents only 1% of total domestic wastewater volume, it contains the majority of the plant-essential macronutrients, including approximately 80% of N, 50% of P, and 60% of K (Vinnerås et al., 2006). Globally, if all urine-derived nutrients were returned to farmland, they could supply up to 25% of agricultural N and P demand (Simha et al., 2023), highlighting the high potential of this stream for circular nutrient management.

3.1.5.3. Future development of raw material availability

The projected availability of human urine as a recoverable raw material for nutrient recycling depends primarily on two factors: demographic trends and the implementation of separate collection technologies.

Since urine production is directly proportional to population size, countries experiencing population decline – such as Lithuania, Latvia, Estonia – may see a decrease in total potential urine volume over time. However, the current availability remains very low, as separate urine collection systems are still rare across the region.

There are nonetheless promising developments. Examples include the installation of urine-diverting toilets at the VA SYD headquarters in Malmö, implemented as part of the REWAISE project, and current ongoing installation of urine separating and diverting systems at the Studenternas IP multi-use stadium in Uppsala, implemented as part of the CiNURGi project. There are also the nutrient recovery systems implemented at the Gebers collective housing project in Orhem, Sweden.

Although these initiatives remain isolated, the growing prioritisation of sustainability and resource recovery in urban planning suggests that separate urine collection technologies could become more widespread in future construction and renovation projects.

3.1.6. Animal manure (liquids and solids)

3.1.6.1. Amounts

According to Eurostat statistics, the total amount of N in livestock manure in the Baltic Sea Region was approximately 2.4 million ton in 2014, excluding Estonia. However, data availability declines after 2014, particularly for Denmark, for which no recent figures are available. In Germany – the country with the largest manure volumes – the amount of N in manure decreased by approximately 13% between 2014 and 2020.

For P, livestock manure in the Baltic Sea Region contained 0.45 million tonnes in 2014. By 2021, data indicate that the P content in manure from Germany had decreased by 21%. Based on these trends, a rough estimate suggests that the current annual amounts of nutrients in manure across the region are approximately:

- 2.1 million tonnes of N (2.4 million minus 13%)
- 0.36 million tonnes of P (0.45 million minus 21%)

These estimates highlight the continued importance of livestock manure as a major nutrient source in the Baltic Sea Region, despite overall declines.

3.1.6.2. Agricultural use

In accordance with the EU Nitrates Directive, livestock manure and its processed forms may only be applied to land for crop fertilisation under regulated conditions. Anaerobic digestion (AD) of manure is practiced throughout the region as a method of stabilising manure for energy and nutrient recycling, however, there is still large potential to increase AD processing.

For example, in Sweden approximately 1.2 million tonnes of manure were treated via AD in 2021 (Statistics Sweden, 2022b), while a total of approximately 22 million tonnes of manure were applied to agricultural land that year.

At the EU level, however, there is a lack of comprehensive and up-to-date statistical data detailing the specific end-uses of manure, including the proportions applied untreated, processed, or disposed of by other means (Lupton, 2017). This data gap complicates efforts to accurately assess nutrient recycling efficiency and to design targeted policies for manure management across member states.

3.1.6.3. Future development of raw material availability

According to Eurostat (2024), the production of manure in the EU has been declining over the past decade. This downward trend is expected to continue in the coming years, driven by structural changes in agricultural production, reductions in livestock numbers and increasing environmental regulations.

These trends imply a gradual reduction in the availability of manure as a raw material for nutrient recycling initiatives, underscoring the importance of optimising the use of existing manure resources and exploring complementary nutrient sources.

3.1.7. Digestate (based on various influent material types)

3.1.7.1. Amounts

According to the European Biogas Association (EBA, 2023), the total production of digestate in Europe was estimated at approximately 31 million tons in 2022, based on biogas production data and conversion factors for biomethane potential. The corresponding nutrient content in this digestate was estimated at 1.7 million tons of N and 0.3 million tons of P.

The top three countries in terms of biogas production capacity – Germany, Denmark, and Sweden – all located in the Baltic Sea Region, accounted for about 49% of the total European biogas output (EBA, 2023), estimated at ~43,000 GWh. Based on this share, the BSR's contribution to digestate-derived nutrients can be roughly estimated at 0.83 million tons of N and 0.15 million tons of P.

In 2022, 67% of European biogas was produced at agricultural biogas plants, where manure and agricultural by-products were the primary substrate. In Denmark, manure comprised over 70% of the feedstock, while Germany relied more heavily on agricultural residues and energy crops. In Sweden, although biogas production is also significant, more than 80% of the substrates consisted of sewage sludge, meaning that a large share of Swedish digestate originates from non-agricultural sources (EBA, 2023).

3.1.7.2. Agricultural use

Digestate is widely used as an effective fertiliser, as anaerobic digestion preserves the total content of N and P while significantly improving nitrogen plant availability – typically by 17-30%, due to the conversion of organically bound N into ammonium (AgroTechnologyATLAS, 2025). At the same time, the organic matter content in digestate is generally 10-15% lower than in the influent material, as a portion of the carbon converted into methane during the digestion process.

3.1.7.3. Future development of raw material availability

Future growth in anaerobic digestion is expected to increase the availability of digestate, which represents a suitable feedstock to produce BBFs. The centralisation of organic waste streams through AD can facilitate further processing steps, such as the production of manure pellets. However, pelletising still requires pre-drying to a dry matter content of approximately 90%, which presents a technical and energy-demanding step. In addition, the broader adoption of such solutions continues to face challenges related to investment costs, logistics, and competition with conventional synthetic fertilisers.

3.1.8. Meat and bone meal

3.1.8.1. Amounts

Meat and bone meal (MBM) is a nutrient-rich co-product of the livestock rendering industry, produced through the processing of animal by-products. According to the EU Animal Byproducts Regulation (Regulation (EC) No 1774/2002), all animal tissue waste from livestock farming, meat processing, and slaughterhouses must be rendered in compliance with strict safety protocols, depending on the material's risk category:

- Category 1 includes high-risk materials such as specific risk material (e.g. brains, spinal cords) and fallen stock (animals that died other than by slaughter). These materials must be disposed of by incineration and cannot be used for fertilisers or animal feed. Recently, by-products of this category have been used as biofuels, replacing coal and petrol carbons.
- Category 2 includes medium-risk materials, such as animals that died from disease, manure, and digestive tract contents. These must be sterilised at 133 °C under 300 kPa pressure for at least 20 minutes, after which they may be composted or anaerobically digested.
- Category 3 includes low-risk materials such as catering residues, meat scraps, and certain precooked food items. These can be processed for use in pet food, composting, or anaerobic digestion after heat treatment at 70 °C for one hour in a closed system.

The proportion of inedible by-products from slaughtered animals - including internal organs and stomach content - varies by species: 49% for cattle, 47% for sheep and lambs, 44% for pigs, and 37% for broilers (Mozhiarasi, V., Natarajan, T.S., 2025).

To estimate potential MBM production from Category 3 across the BSR, calculations were based on livestock population (Eurostat) and species-specific conversion factors that included average live weight, the proportion of live weight converted into retail meat, the amount of rendering material generated per tonne of retail meat, and the typical protein meal yield from rendering (Wiedemann and Yan (2014). As shown in Figure 4, the largest volumes of MBM are generated in Poland, Germany, and Denmark, followed by Finland and Sweden, with smaller contributions from Lithuania, Latvia, and Estonia reflecting smaller national livestock populations.

The total MBM production in the BSR is estimated at approximately 0.92 million tons per year, which could correspond to about 73,000 tons of N and 46,000 tons of P, assuming average nutrient contents of 8% N and 5% P (Jeng, A.S. et al., 2007).

However, not all MBM is available for use in agriculture since a share of MBM, particularly that derived from Category 1 material, is restricted from use as fertiliser and must be disposed of through incineration.

While Category 1 MBM is currently excluded from fertiliser use, future regulatory developments may open the door to using incinerated Category 1 ash, pending European Food Safety Authority risk assessment. For Category 2 materials, direct fertiliser use is already permitted, though practical limitations arise in case of co-processing with Category 1 materials, which triggers stricter disposal requirements under current legislation (European Sustainable Phosphorus Platform [ESPP], 2023).

More detailed data on the proportion of MBM allocated to pet food, energy recovery, and fertiliser production is currently limited but should be considered in future assessments to better understand the nutrient recycling potential of MBM in the BSR. Additionally, national regulations may impose further restrictions or guidelines on MBM usage in agriculture, affecting its actual availability as a bio-based fertiliser input.

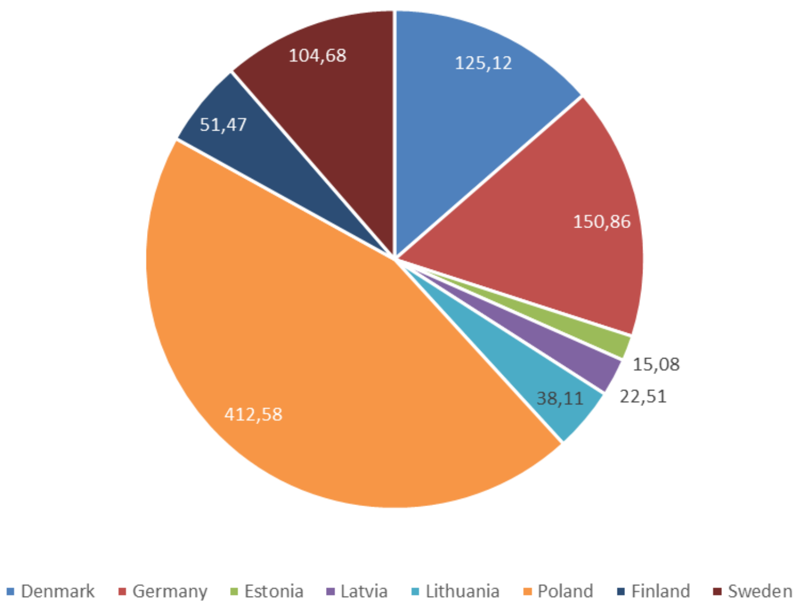

Figure 4: The estimated annual production of MBM in thousand tons across different countries in the Baltic Sea region.

3.1.8.2. Agricultural use

MBM remains a versatile by-product with applications across various sectors, depending on its category. Category 1 MBM, which includes high-risk materials such as specified risk materials and fallen stocks, is strictly prohibited from use in agriculture or animal feed and is typically incinerated or used as fuel in cement kilns due to biosecurity concerns. Category 2 MBM is also banned from use in animal feed but may be processed – following mandatory pressure sterilisation – for use in organic fertiliser production or biogas generation. Category 3 MBM, derived from low-risk materials such as meat scraps and catering waste, has broader applications. It can be used in pet food, and – under strict regulatory conditions – in feed for non-ruminants (e.g., pigs, poultry, and fish) – in certain EU countries, though this remains restricted and subject to traceability and processing requirements. It is also permitted for use as an organic fertiliser, where its high P and N content makes it a valuable input. In addition to these uses, energy recovery and industrial applications for MBM continue to evolve as part of circular bioeconomy.

3.1.8.3. Future development of raw material availability

Changes in animal feed regulations may influence the availability of MBM for fertiliser use. While the use of MBM in livestock feed remains restricted in the EU due to BSE-related (Bovine Spongiform Encephalopathy) concerns, regulatory relaxations introduced since 2021 have reopened pathways for its use in non-ruminant species such as poultry and fish, potentially increasing demand in the feed sector. Although total MBM production is unlikely to rise significantly, its use as a fertiliser is expected to grow, driven by sustainability goals, rising demand for recycled P in both conventional and organic farming, and the development of advanced application methods such as pelletising and blending into complex fertilisers. Nevertheless, logistical constraints and competing markets – such as pet food, feed, and energy – may affect its availability and cost-effectiveness for agricultural applications.

3.2. Market assessment: Indicative evaluation based on costs, savings, costs, and other criteria

To provide an indicative evaluation of the market potential of the longlisted value chains, several key criteria were assessed, including estimated savings, implementation costs, scalability, and regulatory readiness. These were weighted according to their perceived importance, as determined by a poll conducted among Task A1.3 members.

The weight assigned for each criterion is given in Table 8.

Table 8: Weights assigned to the criteria.

Criteria	Weight
Savings and revenues	2
Costs	3
TRL	2
Estimated potential of N in end-product (if all raw material was processed)	3
Estimated potential of P in end-product (if all raw material was processed)	3
Presence of other nutrients/ micronutrients	1
Human skills requirement	1
Flexibility with respect to scale	1
CE-marking possible?	2
Allowed in organic farming?	2

The assessment of savings, costs and other market related factors are presented in Table 8, Table 9, and Table 10. A summary of the market assessment is given in Table 11.

Table 9: Assessment of potential savings and revenues in the respective value chain (+1, 0, and -1 indicates favourable, intermediate, and unfavourable conditions, respectively).

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
Type of savings (according to the baseline)	Impacts on cost of sludge disposal (transport and agricultural spreading) are uncertain – transport to mono-incineration plant required (0).	Reduced cost of mainstream wastewater treatment (N removal to atmosphere) (+1).	Reduced transport cost (+1) and cost of sludge disposal (+1).	Reduced transport cost (+1).	Reduced cost on fertiliser purchases for the farmer (+1).	Reduced transport cost (+1).	There are no savings because the policy requires that all waste be recycled (0).	Reduced transport cost (+1).	Reduced transport cost (+1).	Reduced cost of sludge disposal[b]. (+1).	Reduced cost of mainstream wastewater treatment (+1). Reduced transport cost (+1) and cost of sludge disposal (+1).
Is revenue from sale of end-product or other output possible?	The market is not developed for all types of P-rich end products (0). If sufficient purity, possible potential to sell it for feed production (+1).	Ammonium sulphate: ~1,500 €/ton (commercial price of ammonium sulcate; Business analytiq, 2025) (+1).	Sludge biochar: The market is not developed (0). Carbon credits could be sold (+1)[a]. Sale of excess heat (+1).	Solid and liquid BBF: There is a market; price unknown (+1).	n.a.	Solid and liquid BBF: There is a market; price unknown (+1).	Pellet BBF: ~400 €/t (Hushållningssällskapet, 2022) (+1).	Pellet BBF: There is a market; price unknown (+1).	Pellet BBF ~500 €/t (based on information from the company) (+1).	Dry urine: No active market; price unknown (-1).	Struvite: ~100 €/t (Muys et al, 2021). There is a market (+1).
Competition with other BBFs (in terms of efficiency)	Strong (+1).	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)	Strong (+1)
Competition with mineral fertilisers (in	Strong (+1)	Strong (+1)	Weak (-1).	Weak (-1).	Weak (-1).	Weak (-1)	Medium (0)	Medium (0)	Medium (0)	Strong (+1)	Medium (0)

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
terms of efficiency)											
Summarised savings and revenues assessment	+3	+4	+4	+2	+1	+2	+2	+3	+3	+2	+4

[a]*This has not yet been verified in long term operation*

[b]*Through decreasing the N and P load on centralised WWTPs the sludge production can be reduced.*

Table 10: Assessment of costs in the respective value chain (+1, 0, and -1 indicates favourable, intermediate, and unfavourable conditions, respectively).

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
Type of costs	Machinery. Chemicals. Energy.	Machinery. Chemicals Energy.	Machinery. Energy (fuel needed).	Machinery.	Machinery. Chemicals.	Machinery.	Machinery. Chemicals. Energy (fuel needed)	Machinery. Chemicals. Energy.	Machinery. Energy.	Machinery. Chemicals. Energy. Storage infrastructure	Machinery. Energy (fuel needed). Chemicals.
Cost of raw material (€/ton)	0	0	0	0	0	0	0	0	0	0	0
Investment cost (in relation to the other value chains)	High (-1)	High (-1)	High (-1)	Medium (0)	Low (+1)	Medium (0)	Medium (0)	Medium (0)	Medium (0)	High (-1)	High (-1)
Operation and maintenance cost (in relation to the other value chains)	High (more complex processing) (-1)	Medium to high (more complex processing) (0)	High (more complex processing) (-1)	Medium (less complicated processing) (0)	Low (less complicated processing) (+1)	Medium (less complicated processing) (0)	Medium (less complicated processing, but in several steps) (0)	Medium (not complex processing, but in several steps) (0)	Medium (less complicated processing) (0)	High (collection, transport, processing) (-1)	Medium (more complex processing) (0)
Summarised cost assessment	-2	-1	-2	0	+2	0	0	0	0	-2	-1

Table 11: Assessment of other market-related parameters in the respective value chain (+1, 0, and -1 indicates favourable, intermediate, and unfavourable conditions, respectively).

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
TRL	8 (0)	7 (-1)	8 (0)	9 (+1)	9 (+1)	9 (+1)	9 (+1)	8 (0)	8 (0)	6 (-1)	8 (0)
Estimated potential of N in end - product	Insignificant (-1)	Small (-1)	Small (-1)	Large (+1)	Large (+1)	Large (+1)	Medium (0)	Large (+1)	Large (+1)	Medium (0)	Small (-1)
Estimated potential of P in end-product	Medium (0)	Small (-1)	Medium (0)	Large (+1)	Large (+1)	Large (+1)	Large (+1)	Large (+1)	Large (+1)	Medium (0)	Medium (0)
Presence of other nutrients/ micronutrients	No (-1)	No (-1)	Yes (+1)	Yes, however, not high concentration (0)	Yes, however, not high concentration (0)	Yes, however, not high concentration (0)	Yes (+1)	Yes (+1)	Yes (+1)	Yes (+1)	Yes (+1)
Human skills requirement	Medium. New type of machinery will be required, new type of risk given thermal treatment. However, centralised treatment does not require large number of people to be trained (0).	Medium. New type of machinery, chemicals used. There are available skills with respect to chemical management in the wastewater sector (0).	High. New type of machinery will be required, new type of risk given thermal treatment performed locally (-1).	Low. The separation may be new to local staff but is commonly used for similar substrate (sewage sludge) (+1).	Medium. Handling of acid which may be a new type of task for the local farmer (0).	Low. The separation may be new to local staff but is commonly used for similar substrate (sewage sludge) (+1).	Low. Relatively simple principles. Centralised treatment does not require large number of people to be trained (+1).	Medium. Relatively simple machinery, however, several steps are included in the processing as well as designated treatment of the water vapour generated (0).	Low-Medium. Relatively simple machinery (0).	High. New type of machinery will be required, new type of risk given drying treatment (-1).	Medium. New type of machinery, chemicals used. There are available skills with respect to chemical management in the wastewater sector (0).

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
Flexibility with respect to scale	Low. Assumed to require large scale treatment to achieve cost efficiency (-1).	High. Principles are relatively simple with respect to machinery required. Treatment is performed locally at WWTP (+1).	Low. The current technology providers have standardised sizes adapted to certain sizes of WWTP (-1).	High. Several parallel lines of treatment can easily be installed. AD plants size varies (+1).	High. Principles are relatively simple with respect to machinery required (+1).	High. Several parallel lines of treatment can easily be installed. AD plants size varies (+1).	High. Principles are relatively simple with respect to machinery required (+1).	High. Several parallel lines of treatment can easily be installed. AD plants size varies (+1).	High. Several parallel lines of treatment can easily be installed. AD plants size varies (+1).	Medium. Could be scaled up if using urine diversion in new facilities (cost increase for collection) (0).	High. Principles are relatively simple with respect to machinery required. Treatment is performed locally at WWTP (+1).
CE-marking possible?	Yes (+1)	Yes (+1)	No (-1) (wastewater derived; however, an investigation is ongoing)	Yes (+1)	n.a.	Yes (+1)	Yes (+1), after pre-processing ABP material in accordance with its category	Yes (+1)	Yes (+1)	No (-1)	Yes (+1)
Allowed in organic farming?	No (-1) (wastewater derived)	No (-1) (wastewater derived)	No (-1) (wastewater derived)	Yes (+1) (given accepted raw material)	n.a.	Yes (+1) (given accepted raw material)	Yes (+1)	No (-1) (due to addition of polymer).	Yes (+1) (given accepted raw material)	No (-1) (wastewater derived)	No (-1) (wastewater derived)
Country specific certificates or other registration	PL/EE: certificate/ registration possible in relation to national fertiliser regulation. SE: No targeted regulation available, EoW process	PL/EE: certificate/ registration possible in relation to national fertiliser regulation. SE: No targeted regulation available, EoW process	PL/EE: certificate/ registration possible in relation to national fertiliser regulation. SE: national certificate possible ("Revaq"). DK: sludge	SE/FI: voluntary certificate possible ("Certifierad återvinning"/ "Laatulannoite"). FI: Can be sold under national fertilisation acts (964/2023). EE/PL/LV/DK:	Not relevant since the acidified manure is typically used within the farm.	SE/FI: voluntary certificate possible ("Certifierad återvinning"/ "Laatulannoite"). FI: Can be sold under national fertilisation acts (964/2023). EE/PL/LV/DK:	FI: Can be sold under national fertilisation acts (964/2023). PL: certification needed for trade of product.	SE/FI: voluntary certificate possible ("Certifierad återvinning"/ "Laatulannoite"). FI: Can be sold under national fertilisation acts (964/2023). EE/PL/LV/DK:	SE/FI: voluntary certificate possible ("Certifierad återvinning"/ "Laatulannoite"). FI: Can be sold under national fertilisation acts (964/2023). EE/PL/LV/DK:	DE: not in "positive list", i.e. it cannot be traded as a fertiliser, however, local use can be possible. SE: urine fertilisation is allowed[d].	PL/EE: certificate/ registration possible in relation to national fertiliser regulation. SE/FI: No targeted regulation available, EoW process

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
	may be needed (if no CE-mark).	may be needed (if no CE-mark).	biochar is used locally, with permit from the local municipality.	allowed to trade (EE: under digestate regulation).		allowed to trade (EE: under digestate regulation).		allowed to trade (EE: under digestate regulation).	allowed to trade (EE: under digestate regulation).	PL/EE: certificate/ registration possible in relation to national fertiliser regulation.	may be needed (if no CE-mark).

[c]*Certificate by the Polish Institute of Soil Cultivation based on decision of the Polish Ministry of Agriculture and Rural Development.*

[d]*Urine is viewed as a bio-based fertiliser (under the same regulation as e.g. manure), no specific regulation is available which makes urine fertigation a somewhat grey area.*

f reduced cost compared to mono incineration

Table 12. Summarised market potential scoring for each value chain.

Indicator	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
Savings and revenues	+3	+4	+4	+2	+1	+2	+2	+3	+3	+2	+4
Costs	-2	-1	-2	0	+2	0	0	0	0	-2	-1
TRL	0	-1	0	+1	+1	+1	+1	0	0	-1	0
Estimated potential of N in end-product (if all raw material was processed)	-1	-1	-1	+1	+1	+1	0	+1	+1	0	-1
Estimated potential of P in end-product (if all raw material was processed)	0	-1	0	+1	+1	+1	+1	+1	+1	0	0
Presence of other nutrients/ micronutrients	-1	-1	+1	0	0	0	+1	+1	+1	+1	+1
Human skills requirement	0	0	-1	+1	0	+1	+1	0	0	-1	0
Flexibility with respect to scale	-1	+1	-1	+1	+1	+1	+1	+1	+1	0	+1
CE-marking possible?	+1	+1	-1	+1	n.a.	+1	+1	-1	+1	-1	-1
Allowed in organic farming?	-1	-1	-1	+1	n.a.	+1	+1	-1	+1	-1	-1
Combined score before weighting	-2	0	-2	9	7	9	8	5	9	-4	2
Combined score after weighting	-5	-3	-6	18	17	18	13	10	18	-11	0

3.3. Ranking of the value chains for their market potential

The final ranking of the value chains, derived from the aggregated scoring presented in Table 12, is summarised in Table 13. Notably, the application of weighing factors did not alter the composition of the top six ranked value chains, indicating strong overall performance across multiple criteria.

Table 13: Ranking of the value chains before and after weighting.

Value chain	Ranking before weighting	Ranking after weighting
MTS2	9	9
MCL	8	8
MTS1	9	10
MML	1	1
FCL	5	4
FMS	1	1
IMP	1	5
FMP1	6	6
FMP2	1	1
MCG	11	11
MCS	7	7

3.4. Discussion

From a monetary perspective, most evaluated value chains are likely to incur higher costs than their respective baselines. This is largely due to additional processing steps that introduce investment requirements, labour and maintenance expenses, energy demands, and - in some cases - costs for process chemicals. In contrast, baseline scenarios often represent low-cost waste disposal options with minimal or no operational costs.

Notably, the most mature value chains (TRL 9) tend to rely on relatively simple and low-cost processes. These include phase separation of manure (MML/FMS) and in-field acidification (FCL). Their economic feasibility is supported by minimal infrastructure and operational requirements. Another example is the pelletising of meat and bone meal in the IMP value chain. While this process faces strict regulatory demands concerning raw material handling, it also benefits from higher BBF sale prices due to acceptability in organic farming, creating a commercially viable model.

Value chains with a TRL of 8 generally involve more complex technologies and multiple processing steps. Their market potential varies from low to relatively high, primarily depending on the nutrient content and agronomic value of the final product. In contrast, the least mature case (MCG, TRL 6) currently demonstrates the lowest market potential due to high implementation costs, underdeveloped infrastructure, and a lack of established labelling or certification schemes, despite its high innovation potential.

Another aspect that differentiates the value chains is the type of feedstock. Wastewater and sludge-based value chains may generate cost savings by reducing treatment or disposal expenses. With respect to digestate-based value chains (from manure, municipal food waste, etc), some savings could be achieved through reduced transportation and improved logistics.

However, the main economic driver is often an increased market value due to nutrient concentration and improved handling properties (i.e. use of pellets instead of raw digestate).

A business case analysis by Hermann and Hermann (2021) across seven anaerobic digestion plants in Europe (Italy, Belgium, Germany, The Netherlands, UK and Finland) showed that while nutrient recycling positively contributed to revenues, the direct sale of BBFs played only a minor role. Instead, financial benefits arose from reduced costs in substrate procurement, transport, and digestate handling, and increased income from energy sales. This suggests that nutrient recycling is economically justified when it reduces system-wide costs, rather than when relying solely on BBF sales.

Another obstacle of implementing these value chains is that the willingness to pay for BBFs, in relation to the amount of N or P supplied and their availability, can be assumed to be smaller compared to the same amount of N or P in mineral fertilisers (Moshkin et al., 2023). The demand for BBFs is not only related to the amount of nutrients but also their concentration and form as well as consistency in BBF-quality. Although certain BBF demonstrate competitive characteristics compared to mineral fertilisers - particularly in terms of nutrient form and plant availability - they remain less attractive due to their higher cost of nutrient applied.

Yetilmezsoy et al. (2017) proposed improving the commercial viability of struvite by increasing its market price to €560 per tonne to ensure a viable return on investment. Regulatory costs, such as those associated with CE marking and auditing, can also hinder uptake, although economies of scale could mitigate these per-unit costs over time.

BBF competitiveness is also linked to volatility in global mineral fertiliser markets. Price surges and supply disruptions—like those observed in recent years—may incentivise farmers to explore alternative nutrient sources, potentially improving market conditions for BBFs (Tröster, 2023).

Revenues from BBFs may be higher in niche markets such as home gardening or greenhouse nurseries (Hermann and Hermann, 2021). Entrance into such markets could stimulate the development of value chains, however, they are marginal when considering the total use of mineral fertilisers. It should be highlighted that in most cases we did not have access to exact selling prices of the end-product in any of the cases (this was regarded as confidential information by the companies behind each value chain) which hampers the comparison with mineral fertilisers.

All longlisted value chains have TRLs between 7 and 9, in line with the project's inclusion criteria. However, beyond TRL, market readiness also depends on “market formation” (McConville et al., 2017), which requires adoption by a critical mass of users. In early phases, knowledge dissemination and stakeholder engagement are essential for scaling up.

The estimated potentials of N and P in end-products, i.e. the amounts of N and P which could be contained in end-products if all raw material was processed are given in Annex 2. The numbers were based on very rough estimates and should not be overinterpreted, however, their order of magnitude is relevant to observe, and based on this the end-products of greatest potential are:

- Nitrogen: Slurry acidification in-field (FCL) ~[3] Separated digestate (MML) ~ Settled and separated digestate (FMS) ~ Digestate pellet (FMP2) ~ Digestate pellet with additives (FMP1) > Urine granule (MCG) ~ MBM-pellet (IMP) > Ammonium sulphate solution (MCL) ~ Sludge biochar (MTS1) ~ P-rich product from sludge ashes (MTS2) ~ Struvite granule (MCS)
- Phosphorus: Slurry acidification in-field (FCL) ~ Separated digestate (MML) ~ Settled and separated digestate (FMS) ~ Digestate pellet (FMP2) ~ Digestate pellet with additives (FMP1) ~ MBM-pellet (IMP) > Urine granule (MCG) ~ Sludge biochar (MTS1) ~ P-rich product from sludge ashes (MTS2) ~ Struvite granule (MCS) > Ammonium sulphate liquid (MCL)

It is emphasized that these estimated potentials are without consideration to the plant availability of the N + P nutrients in end-products.

The estimates assumed that all raw material could be processed. This is an optimistic scenario for some of the value chains, especially for the MCG value chain, since it would require a large expansion of urine diverting toilets/ sewage systems which would require very large investments and take a long time if all toilets were to be replaced. A more reasonable idea could be to expand this system in newly built housing. Furthermore, for the MTS2 value chain mono-incineration plants for sludge would need to be established. That also requires large investments and strategic decisions from wastewater utilities.

With respect to future availability of digestate, the evolution of European renewable energy policies has significantly influenced the selection of substrates used in agricultural biogas production. The Renewable Energy Directive (RED I, 2009/28/EC) and its successor, the Revised Renewable Energy Directive (RED II, 2018/2001/EU) have introduced new sustainability criteria, changing the economic viability and regulatory acceptability of different feedstock types:

- RED I (2009/28/EC) provided strong financial incentives for biogas production, primarily through feed-in tariffs and green certificates for renewable electricity. As a result, agricultural biogas plants predominantly used high-yield energy crops such as maize silage, grass silage, and cereal grains, due to their stable supply and high methane potential. In contrast, the use of livestock manure and agricultural residues was limited due to lower biogas yields and higher handling costs. Organic waste constituted only a minor share of the feedstock mix, as policies focused on energy generation rather than nutrient recycling. However, growing concerns about indirect land-use change, competition with food production, nitrogen leaching, and biodiversity loss prompted a reassessment of sustainability standards.
- RED II (2018/2001/EU) marked a significant policy shift toward sustainability, climate mitigation, and circular economy principles. One key change was the restriction of financial support for biogas derived from food and feed crops, reducing reliance on energy crops like maize. Instead, RED II promoted the use of waste- and residue-based feedstocks by offering double-counting toward renewable energy targets. Feedstocks

[3] Sign (~) indicates that the amounts are in the same order of magnitude. More than sign (>) here indicates a larger order of magnitude.

such as animal manure, straw, food industry by-products, slaughterhouse waste, and municipal biowaste gained prominence due to their lower GHG footprints and alignment with circularity goals. This policy evolution elevated the role of digestate not only as a by-product but as a recognised, valuable BBF.

- RED III (2023) further reinforces the transition to circular, waste-based bioenergy systems by explicitly supporting the valorisation of digestate. The directive emphasises the importance of integrating energy production with nutrient recovery, solidifying the role of agricultural biogas as a climate-smart, resource-efficient solution in the EU's broader sustainability agenda.

It is also worth considering the integration of complementary value chains to enhance nutrient recovery potential and overall system efficiency. In municipal wastewater treatment, N is conventionally removed through nitrification-denitrification processes, which convert reactive nitrogen to inert nitrogen gas (N_2), resulting in the loss of valuable nutrients and contributing to greenhouse gas emissions. However, alternative approaches could instead aim to recover nitrogen in usable forms—such as ammonium sulphate—within the treatment process.

Phosphorus, by contrast, is predominantly retained in the solid fraction during wastewater treatment, particularly in sewage sludge. As such, current and future strategies for phosphorus recovery focus on processing these solids to extract usable forms of P, while simultaneously addressing the presence of co-contaminants such as heavy metals, organic micropollutants, and microplastics. Technologies such as sludge pyrolysis (to produce biochar) or chemical processing of sludge ashes (to recover various P-rich products) are examples of promising P-focused value chains.

By strategically combining nitrogen recovery technologies (e.g., ammonia stripping and capture from reject water) with phosphorus recovery technologies (e.g., incineration followed by ash processing, or thermochemical conversion to biochar), nutrient recycling from wastewater can be made more comprehensive and resource efficient. Such integration aligns with the updated Urban Wastewater Treatment Directive (UWWTD), which mandates phosphorus reuse by 2027 and is expected to extend to nitrogen in the future, supporting a shift toward nutrient circularity in wastewater management.

The presence of secondary nutrients and micronutrients is increasingly recognised as essential for achieving balanced fertilisation strategies and maintaining long-term soil health. Elements such as potassium (K), calcium (Ca), magnesium (Mg), boron (B), and sulphur (S) are not only vital for plant development but also play important roles in soil structure, nutrient cycling, and microbial activity. Adequate concentrations of these elements in fertilisers can support improved soil resilience and productivity.

In this regard, the inclusion of K and S in BBFs enhances their competitiveness with complex starter fertilisers (NPKs), particularly given the similarity in application timing. However, the concentration of these additional nutrients is highly dependent on both the feedstock composition and the further processing method.

An important but often overlooked dimension in BBF value chains is the ownership of the raw materials. Ownership not only determines who initiates or invests in processing but also influences the feasibility of establishing the value chain. Considering wastewater or sludge the owner is a utility company/ municipality which historically operates with the main purpose to treat wastewater, i.e. to remove N and P in a way so that the treated wastewater may be released without harm to the environment. Sludge is considered a by-product of this process. However, the updated EU UWWTD, which mandates the reuse of P by 2027 and is expected to address N reuse as well, there is clear policy shift toward treating wastewater as a resource rather than a waste stream. This transition may prompt wastewater utilities to adopt more innovative approaches to nutrient recovery and resource valorisation.

Nevertheless, such shifts may also come with increased treatment costs, potentially leading to higher service fees for residents. In contrast, manure – usually managed by individual farmers – presents a different ownership structure. For a value chain based on manure to be viable, it must be economically attractive at the farm level. In most cases, the additional costs associated with processing manure into BBFs (e.g., drying, pelletising, quality assurance) are not offset by higher product value – except possibly in organic farming systems where certification adds market premiums. Therefore, manure processing is more likely to depend on public subsidies or sharp increases in mineral fertiliser prices to become financially viable.

Beyond legislation and certification, market acceptance of BBFs is heavily influenced by downstream actors, particularly food processors and retailers. These buyers often set their own sourcing requirements, which can shape fertiliser use on farms. For instance, ARLA—the leading dairy cooperative in Denmark, Sweden, and parts of Germany—prohibits the use of any fertiliser derived from wastewater treatment on its suppliers' farms. A similar policy is held by e.g. the Federation of Swedish Farmers ("LRF Mjölk") (LRF Mjölk, 2020). Part of the motivation is a precautionary principle. The precautionary principles could be balanced against risk (to health and environment) but also in relation to what is more economic on a societal level (Ekman Burgman, 2022). However, the dairy companies make their policies independently, which means that a strong consumer pull could be needed for their policies to change.

Balancing precaution with evidence-based risk assessments and societal economic benefits is crucial for developing fair and functional nutrient recycling markets. Until a strong consumer demand for sustainably sourced food drives change, these corporate policies are likely to persist and should be accounted for when assessing market potential and developing BBF-related value chains.

4. Policy environment for the circular economy of nutrients

This chapter explores the policy landscape shaping the circular economy of nutrients, focusing on whether current EU and regional policies steer, support, or incentivise nutrient recycling. The analysis is framed within the broader context of the EU Green Deal, the Farm to Fork Strategy, and HELCOM's Baltic Sea Regional Nutrient Recycling Strategy. Figure 5 illustrates the complex policy framework relevant to nutrient management, highlighting the key institutions, countries, conventions, and regulations that govern nutrient flows across scales.

We examine the policies across the entire nutrient value chain – from the collection and processing of nutrient-rich materials to the marketing and use of BBFs – in order to identify key barriers and incentives. The aim is to understand where current policies create supportive conditions and where gaps or misalignments may be holding back progress.

To synthesise these insights, the chapter also includes a combined assessment of these barriers and incentives through a SWOT-style approach to reflect on how current policy dynamics shaped by broader factors such as environmental change, geopolitical shifts, and economic pressures may create opportunities or pose threats to the future development of policies steering nutrient recycling.

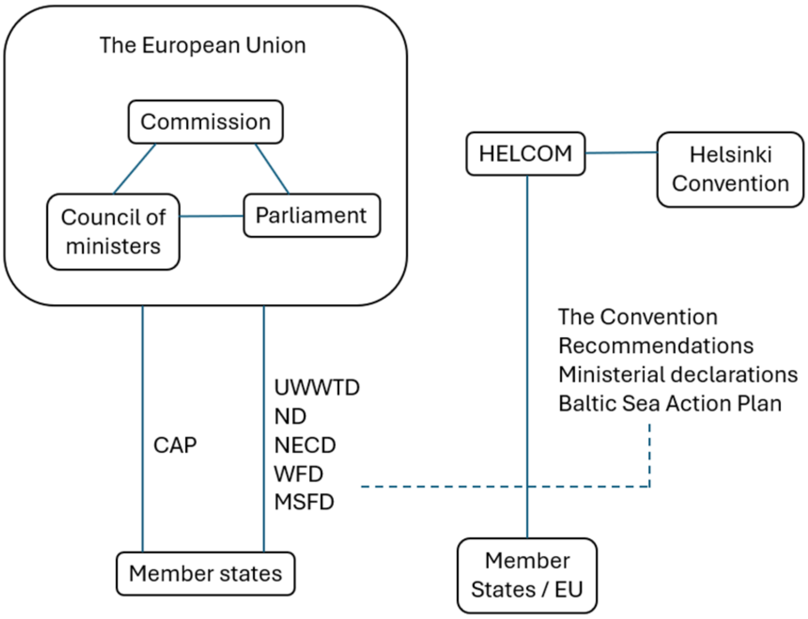

Figure 5: The considered policy framework context of institutions, countries, conventions and main regulations behind the governance of nutrient management. Redrawn from Reusch et al. 2018.

In the final section, we apply this perspective to 11 longlisted cases, each representing a complete nutrient recycling value chain. For each case, we assess relevant policy incentives and barriers, considering how these may influence or limit uptake and scaling. This helps highlight where policies may be enabling or hindering progress, and whether solutions lie at the EU level, within regional frameworks, or require coordination between both.

HELCOM addresses nutrient management via several recommendations and its Baltic Sea Action Plan (BSAP), which sets specific targets for reducing N and P emissions. At the European level, the EU has adopted several directives aimed at improving nutrient management, including the Nitrates Directive, Urban Wastewater Treatment Directive, and Sewage Sludge Directive, among others. A key policy instrument influencing nutrient management in agriculture is the EU Common Agricultural Policy (CAP). Through the CAP, member states develop and implement national measures that often align with HELCOM's recommendations, supporting nutrient reduction efforts in agriculture as part of broader environmental and climate objectives (Reusch et al., 2018)

4.1. Current policy landscape

4.1.1. EU policy frameworks

4.1.1.1. Overview

Nutrient recycling in the EU is governed by a broad and interconnected policy landscape comprising strategies, directives, and regulations aimed at reducing environmental impacts, promoting resource efficiency, and advancing the circular economy. At the strategic level, the Circular Economy Action Plan (2020), a core component of the European Green Deal (2019), sets the overarching direction for waste reduction and sustainable material use. The CAP plays a central role in shaping nutrient inputs and farming practices through subsidies and eco-schemes that promote sustainable land management.

On the legislative side, the Nitrates Directive and Waste Framework Directive establish key legal foundations for nutrient management and recycling. The Urban Wastewater Treatment Directive, recently updated in 2024, introduces stronger requirements for nutrient recovery, particularly P. In parallel, the REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals) governs the use of chemicals in production processes and may affect the use and classification of recycled nutrient products. The Fertilising Products Regulation (EU 2019/1009) provides harmonised rules for CE-marked fertilisers, including criteria under which materials can exit waste status and enter the EU market as fertilising products.

Together, these instruments shape how EU member states design national policies, create market conditions, and channel investments to support nutrient recycling across the value chain – from collection and processing to application in agriculture.

4.1.1.2. Sector-specific policies

Agriculture and animal by-products

The CAP is a key policy framework influencing agricultural practices and nutrient use across Europe. While the basic structure is set at the EU level, member states implement it in diverse ways, resulting in varying national approaches to nutrient management, eco-scheme design, and support for circular practices such as manure processing and nutrient recycling.

The EU Organic Farming Regulation is applied more uniformly but still allows some national differences, especially regarding approved fertilisers and soil amendments. The long-term role of organic farming within EU sustainability strategies, such as the Green Deal and Farm to Fork, is still evolving and may influence future nutrient recycling priorities.

The EU Animal By-Product Regulation is consistently enforced across all member states and plays a critical role in regulating the safe handling, processing, and reuse of animal-derived materials. This regulation is fundamental for enabling the use of certain animal by-products in BBFs, while also ensuring public and environmental safety.

Biogas and biomethane

EU renewable energy legislation plays a significant role in the development of biogas and biomethane, with implementation relatively harmonised across member states. However, frequent revisions to key directives, such as the Renewable Energy Directive (RED), have created uncertainty and delayed investment decisions, particularly for long-term infrastructure projects.

Current EU policy framework is primarily focused on regulating and incentivising production, while comprehensive policies for end-use sectors - such as transport, heating, and industrial applications – are still evolving. This creates a regulatory gap that can limit demand-side growth for biogas-based solutions.

Emerging strategies, including the EU Methane Strategy (2020) and REPowerEU initiative (2022), aim to accelerate biogas deployment by emphasising its role in energy security, climate mitigation, and circular economy goals. Transport-related legislation, both at EU and national levels, further influences demand by integrating biogas use within decarbonisation strategies for mobility, complementing broader objectives under the RED framework.

Chemicals

The REACH regulation governs the registration and use of chemical substances within the EU and plays an important role in ensuring safety and traceability. While REACH aims to protect human health and the environment, compliance can be costly and complex, particularly for producers of recycled products.

Although sewage sludge, compost and digestate are currently exempt from REACH registration due to their classification as waste or natural substances, this status has been subject to ongoing debate. If these materials were to lose their exemption – as part of a broader effort to harmonise chemical safety across product streams – recycled nutrient products could face additional regulatory hurdles. This may affect their marketability and increase the administrative burden on producers, particularly small and medium-sized enterprises (SMEs).

As the EU continues to update its chemicals strategy under the European Green Deal, future revisions to REACH could significantly influence the regulatory landscape for bio-based fertilisers and other nutrient recycling solutions. The European Commission is due to present a proposal to update the REACH Regulation by the end of 2025. The aim of the update is to simplify the Regulation and reduce the administrative burden.

Circular economy

In the context of the Clean Industrial deal (2025), the European Commission is developing new regulatory initiatives to support the circular economy and bioeconomy, aiming to strengthen the EU's transition toward more sustainable resource use. At present, there are no binding circular economy targets, but existing EU strategies – such as the Circular Economy Action Plan and the EU Bioeconomy Strategy – already influence the sector-specific legislation and funding programmes across member states.

These strategic frameworks guide the design of policies, investments, and innovation efforts to close material loops and promote resource efficiency, including in the field of nutrient recycling. The circular economy and bioeconomy are also expected to remain prominent themes under the new European Commission's mandate.

At the national level, several member states have taken proactive steps. For instance, Finland has adopted ambitious national strategies for both circular economy and bioeconomy, offering valuable models for integrating nutrient recycling into broader sustainability agendas. Such national initiatives can support the EU's goals by demonstrating how policy coherence, stakeholder engagement, and investment planning can drive practical progress on the ground.

Climate policy and carbon removals

The EU Climate Law establishes legally binding climate targets, requiring member states to adopt corresponding measures at the national level. These national frameworks are increasingly supported by sector-specific climate strategies, such as Finland's voluntary agriculture sector roadmap, which outlines pathways for reducing emissions within farming and land use. National governments also provide financial support mechanisms to encourage emissions reductions across various sectors, complementing EU-level initiatives. By summer 2025, the European Commission will submit a proposal for measures to help the EU achieve its 2040 climate target.

A notable recent development is the adoption of the EU Carbon Removals and Carbon Farming Certification (CRCF) Regulation, which introduces a voluntary, EU-wide certification framework for carbon removals. This includes both carbon farming and long-term carbon storage in products, supporting the scaling of nature-based and technological solutions for achieving climate neutrality.

Environmental legislation and nutrient recycling

Environmental directives remain central to advancing nutrient recycling in the EU. The Nitrates Directive, despite its age, continues to be consistently implemented across member states and serves as a key instrument for controlling agricultural nutrient emissions. Its planned update is particularly relevant, as it may further align the directive with the EU's circular economy and climate objectives.

The Sewage Sludge Directive, though outdated, still provides a common regulatory baseline for all member states regarding sludge management. A revision is also anticipated, which could bring much-needed updates to better reflect current technological and environmental standards such as stricter limit values for heavy metals and maybe new limit values for organic harmful substances.

The Water Framework Directive (WFD) remains a cornerstone of EU environmental legislation, providing a broad legal foundation for water quality and pollution prevention. It plays an indirect but influential role in shaping nutrient management strategies.

Most notably, the Urban Wastewater Treatment Directive (UWWTD) was updated in 2024 to include enhanced requirements for energy efficiency and nutrient recovery. These updates mark a significant step toward embedding circular economy principles in wastewater and biogas systems, reinforcing the importance of nutrient recycling in achieving broader sustainability goals.

Fertilisers

The EU Fertilising Products Regulation provides the framework for placing CE-marked fertilisers on the EU market and is uniformly applied across all member states. However, countries retain the right to enforce their own national fertiliser legislation, resulting in a fragmented regulatory landscape. This patchwork of national rules can create challenges for producers and users of bio-based and recycled fertilisers, particularly when it comes to market access, product classification, and compliance requirements.

Finance

The European Union offers a range of financial instruments aimed at support innovation, research, and infrastructure development in nutrient recycling and circular economy practices. Key EU-level programmes include Horizon Europe, which funds research and innovation; LIFE, which supports environmental and climate action projects; and Interreg, which promotes cross-border collaboration in regional development, including sustainable resource management.

In addition to EU-level programmes, member states provide national funding mechanisms, such as investment grants, subsidies, and support schemes for biogas production and renewable energy use. These national instruments often complement EU funding, helping to accelerate the implementation of nutrient recycling technologies and support the development of market-ready solutions. The CAP is also very relevant part in the finance framework of the nutrient recycling.

EU and national policy trends

The European Commission's five-year work programme outlines a broad set of ongoing and upcoming policy initiatives relevant to nutrient recycling and circular economy goals. In February 2025, the publication of the Clean Industrial Deal Communication reaffirmed the EU's commitment to a sustainable and competitive industrial transformation, including the promotion of circular resource use and emissions reduction across sectors.

At the national level, governments across the EU develop their own complementary strategies and policy frameworks, which can significantly influence how nutrient recycling is prioritised and implemented. A particularly relevant initiative on the horizon is the proposed EU Soil Law, developed under the Healthy Soils strategy. This legislation aims to establish monitoring requirements for member states regarding soil health indicators, which could drive stronger attention to sustainable fertilisation practices, organic matter management, and the use of BBFs in agriculture.

Waste policy and nutrient recycling

The EU Waste Framework Directive serves as the foundation of waste legislation across the EU, providing a harmonised framework that member states must follow. Closely linked to the Industrial Emissions Directive (IED), it sets the core principles for waste management and environmental permitting, including for facilities such as recycling and nutrient recovery plants. Under this directive, member states are required to prepare national waste management plans, which often include specific strategies for biowaste and organic recycling. The directive also sets mandatory separate collection requirements for biowaste in members states. A key component of the directive is the development of End-of-Waste (EoW) criteria – rules that define when a recovered material ceases to be waste and becomes a product. These criteria are especially relevant for recycled fertilisers and other nutrient-containing materials based on municipal and industrial wastes, as they determine whether such substances can be marketed and used as fertilising products rather than being handled as waste.

4.1.2. HELCOM's policy framework on nutrient recycling

4.1.2.1. Overview

The Baltic Marine Environment Protection Commission – commonly known as HELCOM or the Helsinki Commission – is an intergovernmental organisation composed of the EU and the nine Baltic Sea coastal countries. It oversees the implementation of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention).

HELCOM provides a platform for regional cooperation on marine protection and sustainable use of the Baltic Sea. It integrates policy and science to address a wide range of issues, including biodiversity, eutrophication, hazardous substances, maritime traffic, fisheries, spatial planning, and both land- and sea-based pressures.

Functioning across different levels of governance, HELCOM engages technical experts, national authorities, agency managers, and ministries. It plays a key role in supporting transboundary cooperation, offering regional infrastructure for data sharing, tools for policy implementation, and frameworks for joint assessments.

HELCOM's decision-making process is science-based and follows a bottom-up approach. Typically, a Contracting Parties (CPs) raises an issue, triggering technical work by Expert Groups composed of national experts. These groups develop the scientific and technical background for action. HELCOM Working Groups (WGs) then translate these findings into draft recommendations, strategies, or actions. Final approval is given by the Heads of Delegation ensuring alignment with HELCOM's strategic objectives. Major policy decisions – such as those linked to long-term goals – are endorsed at either the Annual HELCOM Meeting or the Ministerial Meeting held every three years.

This structured and participatory process ensures that HELCOM's policies are evidence-based, transparent, and supported by all Contracting Parties, reinforcing its leadership in safeguarding the Baltic Sea.

4.1.2.2. The Helsinki Convention

The Helsinki Convention is the core legal instrument guiding protection of the Baltic Sea. It outlines binding commitments for all Contracting Parties through 38 Articles and seven Annexes (I-VII), which detail technical standards and regulatory measures.

Of particular relevance to nutrient recycling is Annex III, Part II, which focuses on the Prevention of Pollution from Agriculture. Last amended in 2021, this section establishes clear criteria and requirements aimed at reducing nutrient runoff from agricultural activities. It places a strong emphasis on the application of Best Environmental Practice (BEP) and Best Available Technology (BAT) as guiding principles for pollution prevention.

These provisions form a crucial part of the regional framework for nutrient management, supporting coordinated efforts to curb eutrophication and promote sustainable agricultural practices in the Baltic Sea Region.

4.1.2.3. Action Plans and Strategies

The Baltic Sea Action Plan (BSAP)

The Baltic Sea Action Plan (BSAP) is HELCOM's central strategic programme to restore and safeguard the marine environmental of the Baltic Sea. First adopted in 2007, the BSAP sets out concrete actions to combat eutrophication, biodiversity loss, hazardous substances, and negative impacts from sea-based activities.

In response to persistent environmental pressures and the failure to meet the original 2021 objectives, the BSAP was updated in 2021, retaining its ambition while integrating new measures to address emerging challenges, including climate change.

The updated BSAP is structured around four thematic segments:

- Biodiversity: Aims for a healthy and resilient marine ecosystem through enhanced protection of species and habitats, expansion of marine protected areas (MPAs), and mitigation of human-induced pressures.
- Eutrophication: Aims to reduce nutrient loading – particularly nitrogen and phosphorus – through Maximum Allowable Inputs (MAI) and Nutrient Input Ceilings (NIC), with the ultimate goal of eliminating excessive algal blooms and hypoxia.
- Hazardous substances and litter: Focuses on the reduction of toxic pollutants, microplastics, and pharmaceutical residues, alongside improved wastewater treatment and bans on harmful chemicals.
- Sea-based activities: Promotes sustainability in maritime industries, addressing pollution from shipping, responsible fisheries, and reduction of underwater noise.

In addition to these core areas, the BSAP includes cross-cutting themes such as climate change adaptation, monitoring, maritime spatial planning, economic and social analysis, and financing. Climate change is explicitly recognised as a multiplier of existing threats, calling for flexible and adaptive implementation.

Accountability and progress tracking are supported by the HELCOM Explorer tool, with milestone evaluations planned for 2025 and 2029, and reviews during HELCOM Ministerial meetings. The plan is closely aligned with global and regional frameworks, including the EU Marine Strategy Framework Directive, the European Green Deal, and the UN Sustainable Development Goals (SDGs).

By 2030, the BSAP actions should be fully implemented, ensuring that the Baltic Sea moves towards good environmental status.

The Baltic Sea Regional Nutrient Recycling Strategy

Adopted in 2021, the Baltic Sea Regional Nutrient Recycling Strategy aims to promote sustainable nutrient management across the region by reducing nutrient losses, improving nutrient use efficiency, and enhancing circular economy practices. The strategy responds to the ongoing challenge of eutrophication, primarily driven by excess phosphorus and nitrogen, contribute to eutrophication entering the Baltic Sea.

Its overarching vision is that nutrients are sustainably managed in all HELCOM countries, supporting agricultural productivity while minimising environmental impacts – particularly nutrient losses to the Baltic Sea.

The strategy is structured around six key objectives:

1. Position the Baltic Sea region as a model for nutrient recycling by increasing nutrient use efficiency and circulating available resources.
2. Reduce environmental impacts by closing nutrient cycles, lowering GHG and ammonia emissions, and improving soil quality.
3. Ensure safe nutrient recycling by managing hygiene risks and contaminants and supporting research into safe application practices.
4. Foster knowledge exchange through education, research, and innovation in nutrient recovery technologies.
5. Create economic opportunities by supporting circular economy business models and improving the economic viability of nutrient recycling.
6. Enhance policy coherence through regulatory updates and improved governmental cooperation.

To achieve these objectives, the strategy outlines several concrete implementation measures including:

- Improving fertilisation planning tailored to crop and soil needs.
- Promoting the use of manure and organic fertilisers, while encouraging innovation in nutrient recovery technologies.
- Developing incentives and market mechanisms for recycled nutrients products.
- Enhancing wastewater treatment technologies to better recover phosphorus and nitrogen.
- Supporting research and demonstration projects that explore nutrient recovery and emissions reduction.

Monitoring and follow-up are integrated into the BSAP, ensuring coherence between regional nutrient management goals and broader environmental objectives.

Overall, the strategy contributes not only to eutrophication mitigation, but also to climate change adaptation, agriculture resilience, and long-term food security in the region.

4.1.2.4. Valid recommendations

A key role of HELCOM is issuing Recommendations, which serve as the main policy instruments for addressing pollution and promoting environmental protection across the Baltic Sea Region. These recommendations are implemented by Contracting Parties through their national legislation. Since the 1980s, HELCOM has adopted approximately 260 Recommendations, covering a wide range of environmental topics. Implementation progress is regularly monitored and evaluated through reporting, enabling HELCOM to identify effectiveness, gaps, and areas for improvement.

Some of the most significant updates affecting nutrient recycling are presented in the following paragraphs.

HELCOM Recommendation – Amendments to Part II Annex III of the Helsinki Convention

Adopted in October 2021, this recommendation revises Annex III, Part II of the 1992 Helsinki Convention, which sets criteria and measures for preventing pollution from land-based sources, with a specific focus on agriculture. The updates introduce enhanced measures that align with Best Environmental Practice (BEP) and Best Available Technology (BAT), aiming to reducing nutrient losses, improve manure management, and promote sustainable agriculture in the Baltic Sea Region.

Key elements of the updated regulation include:

- Improved Nutrient Management: Contracting Parties must ensure the efficient use of fertilisers and organic residuals. Limits are set for nutrient application: no more than 170 kg N/ha/year and 25 kg P/ha/year from livestock manure. Applications must align with crop nutrient needs and be avoided during unsuitable conditions (e.g. frozen, waterlogged, or snow-covered soils). A nutrient balance approach is required to match inputs with outputs.
- Manure Storage and Handling: Manure must be stored in leak-proof and environmentally safe facilities for a minimum of six months. Covered storage is recommended to reduce emissions. Temporary field storage is permitted under strict conditions to prevent nutrient losses.
- Livestock Density and Farm Location: Farms should maintain livestock densities with available land to prevent nutrient surplus. The siting and construction of animal housing must avoid groundwater and surface water pollution.
- Reduction of Ammonia Emissions: Measures include optimising animal feed, improve manure storage and application techniques, and covering slurry tanks to minimise volatilisation and emissions.

- Promotion of Nutrient Recycling: Nutrient recycling is explicitly encouraged. Contracting Parties are urged to: develop national nutrient recycling plans; monitor and report on organic residual flows; and support market development of recycled fertiliser products.
- Environmental Permits for Large Livestock Farms: Farms exceeding the threshold of 40,000 poultry, 2,000 pigs, or 400 cattle require environmental permits to ensure comprehensive pollution control.
- Monitoring and Evaluation: Contracting Parties must implement systems to track progress, assess effectiveness, and identify gaps in the implementation of agricultural pollution control measures.

This updated recommendation significantly strengthens HELCOM's approach to agricultural nutrient management. It directly supports the goals of the BSAP and aligns with broader EU directives and national environmental strategies, thereby reinforcing regional efforts to curb eutrophication and promote circular use.

HELCOM Recommendation 41/3 - Use of National Manure Standards

Adopted in 2024, this recommendation aims to improve manure management by promoting the development and consistent use of accurate manure national standards across all HELCOM Contracting Parties. By harmonising nutrient content values for manure, the recommendation supports more precise fertilisation planning, helps prevent over-application of nutrients, and contributes to reducing nutrient losses to the Baltic Sea.

Key elements of the recommendation include:

- National manure standards must be reviewed and updated every four years, considering regional climate conditions, livestock sector characteristics, and the best practices.
- The standards are to be used at the farm level to support nutrient budgeting and fertiliser application planning, ensuring compliance with both national and HELCOM nutrient targets.
- Guidelines for manure sampling and analysis are included, requiring the testing of N, P, and K. These measures aim to improve nutrient use efficiency and reduce the dependency on mineral fertilisers.
- National manure standards should be integrated into environmental monitoring systems to track emissions (e.g. ammonia, GHGs) and nutrient flows. The recommendation also encourages the role of manure in nutrient recycling and the circular economy.
- HELCOM urges cross-country collaboration and information exchange on manure management. Countries are required to report every four years on updates to their manure standards and implementation progress.

HELCOM Recommendation 42-43/5 - Mitigation of Ammonia Emissions from Agriculture

Adopted in 2024, this recommendation replaces the earlier HELCOM Recommendation 24/3, significantly strengthening regional efforts to reduce ammonia emissions from agriculture. Since ammonia contributes to nitrogen deposition in the Baltic Sea and impacts both air and water quality, this updated recommendation focuses on improving nitrogen efficiency and reducing emissions from manure management.

Main objectives and measures:

- Integrated Nitrogen Management: the recommendation promotes a systems approach to N use, aiming to retain more N within the soil-plant system and reduce atmospheric losses.
- Key Mitigation Practices:
    - Adjusting livestock feed to reduce nitrogen excretion.
    - Covered and leak-proof storage to prevent volatilisation.
    - Low-emission application techniques, including trailing hoses, manure injection, and acidification.
    - Housing practices such as frequent manure removal, ammonia-absorbing bedding, and improved ventilation systems to reduce in-barn emissions.
- Nutrient Recovery and Processing: the recommendation emphasises the role of manure processing technologies in reducing emissions and enhancing circularity. Methods such as anaerobic digestion, solid-liquid separation, and pelletising are promoted as effective tools for both emission control and nutrient use.
- Monitoring and Research: Contracting Parties are required to establish monitoring systems to measure agricultural ammonia emissions, supported by data collection and modelling. The recommendation also calls for investment in research and development of innovative nitrogen management solutions.
- Reporting Requirements: Countries must report every four years on the implementation status of ammonia mitigation measures and progress toward emission reducing targets.

4.1.2.5. Guidelines and policy briefs

Guidelines on Fertilisation Planning and Nutrient Accounting

Adopted in February 2024, these HELCOM guidelines aim to enhance nutrient management at the farm level by promoting fertilisation planning and nutrient balance calculations. The guidelines are designed to support the implementation of several key actions under the BSAP, including the reduction of nutrient surpluses, improved nutrient use efficiency, and the introduction of mandatory nutrient accounting practices.

The guidelines focus on two complementary tools:

1. Fertilisation planning

   Fertilisation planning helps match nutrient applications to crop needs, considering soil properties, climatic conditions, and regulatory constraints. Key recommendations include:

- Pre-season planning for nitrogen and long-term planning (e.g. crop rotation-based) for phosphorus.

- Legal compliance, including maximum allowable nutrient application rates, spreading times, and appropriate fertiliser types.
- Soil analysis to determine phosphorus levels, pH, nitrogen content, and other soil properties.
- Crop-specific requirements including yield potential, crop rotation, biological nitrogen fixation, and rotational effects.
- Fertiliser application methods, encouraging precision technologies, correct timing, and an informed choice between mineral and organic fertilisers.

2. Nutrient Balance Calculation

   Nutrient balances offer a way to assess nutrient inputs and outputs and guide improvements in fertilisation practices. Two methods are recommended:

- Farm-gate balance: Evaluates total nutrient flows entering and leaving the farm, including crops, livestock feed, fertilisers, and products. It provides an overview of nutrient use efficiency but does not identify specific nutrient losses.
- Field balance: Calculates nutrient budgets for individual fields, offering more site-specific insights, though it typically excludes livestock nutrient contributions.

  Both balances are usually calculated for N and P, expressed as kg per hectare per year. Reference data from similar farms can be used for benchmarking.

HELCOM Contracting Parties are expected to report on national implementation of these guidelines in the BSAP progress reviews scheduled for 2025 and 2029. Reporting should include which nutrient balance methods are used, how they are integrated into policy frameworks, and the extent of their application at the national level.

These guidelines are a key instrument for reducing agricultural nutrient pollution, promoting efficient fertiliser use, and supporting the transition to more sustainable and circular food systems in the Baltic Sea Region.

4.2. Analysis of barriers, Incentives and the Operating Environment Ahead

This section examines key policy-related barriers and incentives affecting three stages of the nutrient recycling value chain: collection, processing, and marketing and use. It also highlights opportunities for improving policy frameworks to support the development of a circular nutrient economy. A SWOT-style approach was applied to assess strengths, weaknesses, threats and opportunities influencing future policy development. A central consideration is whether the identified challenges can be addressed through national legislation, EU-level policy, or a combination of both. The analysis is based on discussions held during a CiNURGi internal workshop and contributions from a designated project partner subgroup.

4.2.1. Collection

4.2.1.1. Policy Barriers

At the waste collection stage, the classification of some nutrient-containing materials, especially manure, complicates their recycling efforts by adding to the administrative burden for actors trying to manage these resources. Many industries producing side streams lack awareness or do not perceive themselves as part of the circular nutrient economy. Without a clear sense of responsibility or incentive to participate, the volume and quality of collected materials will not develop.

Separate collection and on-site storage come with considerable costs, which are rarely compensated or incentivised. Sanitary regulations, though important for safety, further increase bureaucracy and discourage actors from engaging in nutrient recovery efforts. Additionally, reporting and accounting systems for waste are often based on abstract calculations rather than practical, real-world conditions, making compliance difficult. A general lack of producer responsibility in existing policies weakens the incentive for those generating nutrient-rich side streams to ensure that materials are properly collected and recycled.

4.2.1.2. Policy incentives

Despite these barriers, several policy developments support more efficient and sustainable collection systems. EU programmes such as Horizon Europe and national innovation schemes support R&D and pilot projects to test and optimise collection systems. Biogas production is widely recognised as a key technology for managing organic side streams and plays an important role in linking collection to processing and recycled fertiliser production. The EU Circular Economy Action Plan and the forming Act provides a strategic framework that encourages initiatives to improve material recovery across sectors. Additionally, instruments that promote food and fodder self-sufficiency agendas, by increasing demand for locally sourced organic fertilisers, indirectly contributing to collection of organic materials for recycling. The waste framework directive poses mandatory separately collection requirements for biowaste in the members states. Separately collected biowaste should be recycled according to the waste hierarchy, i.e. in practice, into fertilizer products and growing media.

4.2.1.3. Opportunities

There is significant potential for policy innovation in the area of nutrient-rich material collection. Strengthening international cooperation could help harmonise standards and regulatory practices across borders, facilitating the movement, classification, and reuse of organic resources.

Developing regional biomass flow maps would support more targeted legislation and investment planning, helping to optimise collection logistics and boost material circulation. As collection systems become more efficient and integrated into supply chains, new business opportunities may emerge, particularly for service providers specialising in collection, pre-treatment, and transport of organic waste streams.

4.2.1.4. Threats

Complex and inconsistent policies pose a risk of creating confusion or resistance among industries that are not yet familiar with circular nutrient practices. While environmental regulations are essential for ensuring safety and sustainability, they can also introduce additional administrative burdens that may discourage engagement – particularly if actors perceive them as disconnected from practical realities. Unless better aligned with circular economy goals, such as requirements risk becoming barriers rather than enablers, potentially slowing innovation and uptake of nutrient recycling solutions.

4.2.2. Processing

4.2.2.1. Policy barriers

In the processing phase, companies encounter several regulatory and financial challenges that hinder the advancements of nutrient recycling initiatives. Accessing EU funding instruments often proves complex, particularly for smaller businesses or first-time applicants, thereby impeding investment in innovative nutrient recovery technologies. Additionally, certain regulations are outdated or misaligned with circular economy objectives. For instance, the current, outdated sewage sludge directive does not adequately reflect the needs of modern nutrient recycling practices. Moreover, the EU Fertilising Products Regulation (FPR) excludes specific valuable materials, such as certain animal by-products, from being used in CE-marked fertilisers, limiting the utilisation of potentially beneficial nutrient sources. Regulatory requirements for incineration can also escalate costs when raw materials are still classified as waste, further reducing the financial viability of processing operations.

Profitability remains a central concern, as biogas plants and other processing technologies often struggle to operate sustainably under current conditions where the regulatory environment and market demand do not sufficiently reward the added value of nutrient recovery.

Furthermore, the circulation of agri-biomass is not adequately incentivised within existing policy frameworks, leaving a significant gap in support for this segment of the nutrient recycling system.

4.2.2.2. Policy incentives

Despite these challenges, emerging policy instruments offer promising support for nutrient recycling processes. The revised Urban Wastewater Treatment Directive, set to enter into force in 2025, introduces provisions for improved sludge management, aligning wastewater treatment more closely with circular economy principles. This includes encouraging the recovery of valuable resources from sewage sludge and ensuring that sludge management routes conform to the waste hierarchy. Additionally, the EU Circular Economy Action Plan continues to support efforts to close nutrient loops through processing and resource recovery, fostering innovation and investment in nutrient recycling technologies. National initiatives promoting self-sufficiency further drive demand for local, recycled nutrient sources, creating market opportunities for nutrient recovery processes.

4.2.2.3. Opportunities

There is significant potential for policy innovation and enhanced international collaboration to advance nutrient processing. As technologies evolve, they offer more efficient and cost-effective methods for recovering nutrients from organic materials. Financial mechanisms, such as carbon credits, could incentivize adoption by providing tangible rewards for environmental performance. With appropriate support, these tools could facilitate the broader use of recycled nutrient products and strengthen the business case for investment in processing infrastructure.

4.2.2.4. Threats

Decision-making regarding wastewater treatment technologies remains complex, involving multiple regulatory layers and potentially conflicting objectives. In the absence of clear long-term policy support or consistent incentives, companies may be reluctant to invest in new processing technologies nor improving the existing ones. This uncertainty could hinder progress and result in continued reliance on outdated or suboptimal practices.

4.2.3. Marketing and use

4.2.3.1. Policy barriers

The marketing and use of recycled nutrient products face both structural and perceptual challenges. A significant gap is the absence of clear policy targets for the use of recycled fertilisers. Without mandate goals, the sector lacks direction and momentum, leading to limited market demand. Consumer familiarity and trust in these products remains low, with negative perceptions, especially around safety and effectiveness, hindering adoption among both farmers and end users. This is especially evident in the strict limits placed on wastewater-derived products. Additionally, the high costs associated with fulfilling audit and certification requirements, such as CE-marking, pose substantial barriers, particularly for small-scale facilities, discouraging broader participation.

4.2.3.2. Policy incentives

Despite these challenges, several policy incentives are emerging to support the adoption of recycled nutrient products. Some EU member states and HELCOM Contracting Parties have proposed fiscal incentives, such as tax reductions for recycled fertilisers, to enhance their competitiveness relative to mineral alternatives. Organic farming regulations acknowledge certain organic fertilisers derived from secondary sources, creating differentiated markets for some recycled products. The Common Agricultural Policy (CAP) provides support for circular practices in agriculture, including the use of recycled nutrients; however, implementation varies between members states. Emerging incentives also reward farmers for adopting recycled fertilisers, facilitating the transition. Furthermore, the EU Carbon Removal Certification Framework (CRCF) offers a voluntary certification scheme for carbon removals, including carbon farming practices that enhance carbon sequestration and storage in solids. This framework can facilitate access to voluntary climate benefits. Public procurement and eco-labelling schemes are additional tools that could help build trust and demand for recycled nutrient products.

4.2.3.3. Opportunities

Upcoming revisions of the CAP present opportunities to strengthen support for the use of recycled fertilisers across the EU. As environmental awareness grows and the costs of synthetic fertilisers fluctuate market-driven demand for sustainable alternatives is likely to increase. This shift could pave the way for new business models and a more robust recycled fertiliser sector, especially if supported by aligned policy measures.

4.2.3.4. Threats

Recycled fertilisers often remain less competitive than mineral fertilisers without subsidies or other financial support. As long as this price gap persists, adoption is likely to remain limited. Moreover, restrictions on wastewater-derived fertilisers in grain trade further reduce their attractiveness and marketability, particularly for farmers engaged in export-oriented food production.

4.3. Scoring of the longlisted cases

As part of the assessment, an evaluation framework was developed for the 11 longlisted value chain cases. This framework identifies key EU policy-related barriers (-) and incentives (+) pertinent to nutrient recycling, providing a structured approach to assess each case.

4.3.1. Barriers (B)

The following barriers have been identified:

- B1: The EU Organic Farming Regulation - The process for approving recycled materials in organic farming is often slow and lacks clarity, hindering the integration of innovative nutrient sources.
- B2: EU Fertilising Products Regulation - The approval process for new materials and processes under the FPR is complex and time-consuming. Additionally, the requirements for CE-marking involve high costs, particularly burdensome for small-scale producers.
- B3: Waste Framework Directive - The criteria for obtaining End-of-Waste (EoW) status are not harmonized across Member States, leading to inconsistencies that especially in the case of nutrient-containing municipal and industrial wastes complicate the classification and movement of recycled nutrient products.
- B4: Fiscal and Market Policy - There is a lack of robust fiscal incentives to promote the use of recycled nutrients, making them less competitive compared to conventional fertilisers.
- B5: Sewage Sludge Directive - The outdated nature of this directive contributes to the rejection of wastewater-derived fertilisers in agriculture, fuelled by concerns from consumers and the food industry regarding safety and quality.
- B6: CAP implementation - Although the EU's Circular Economy targets for nutrients are intended to be achieved through measures outlined in Member States' CAP Strategic Plans, the implementation often falls short, lacking the necessary ambition and coherence.

4.3.2. Incentives (I)

Conversely, several incentives have been identified that support nutrient recycling efforts:

- I1: The European Green Deal (Farm to Fork, Biodiversity Strategy, EU Circular Economy Action Plan) – These initiatives set ambitious targets for nutrient recycling, including a 50% reduction in nutrient losses by 2030 while maintaining soil fertility, leading to a targeted 20% reduction in fertiliser use.
- I2: Urban Wastewater Treatment Directive (UWWTD) - The revised UWWTD includes specific targets for the recovery of phosphorus and nitrogen, aligning wastewater treatment processes with nutrient recycling goals.
- I3: The EU Organic Farming Regulation - The regulation promotes the recycling of plant and animal by-products, facilitating the inclusion of certain recycled nutrients in organic farming practices.
- I4: EU Critical Raw Materials List – The designation of phosphorus as a critical raw material increases policy focus on its recovery and reuse, encouraging investment in recycling technologies.
- I5: EU Carbon Removals and Carbon Farming Certification (CRCF) – This framework offers economic viability for the production of sludge biochar and similar products through the potential sale of carbon credits, incentivizing practices that contribute to carbon sequestration.

Table 14 compiles these identified barriers and incentives into a matrix used to evaluate the 11 longlisted cases. For each value chain, the matrix assesses whether the aforementioned barriers or incentives create a positive (+) or negative (-) policy environment, providing a comprehensive overview of the regulatory landscape affecting nutrient recycling initiatives.

Table 14: Ranking of the value chains for policy-related barriers and incentives.

Value chain	B1	B2	B3	B4	B5	B6	I1	I2	I3	I4	I5	Total
MTS1	-1	-1	-1	-1	-1	-1	+1	+1	0	+1	+0,5	-2,5
MML	0	0	0	-1	0	-1	+1	0	+1	+1	0	+1
FCL	-1	0	0	-1	0	-1	+1	0	0	0	0	-2
FMS	0	0	0	-1	0	-1	+1	0	+1	+1	0	+1
MCL	-1	0	-1	-1	-1	-1	+1	+1	0	0	0	-3
MTS2	-1	0	0	-1	-1	-1	+1	+1	0	+1	0	-2
FMP1	-1	0	0	-1	0	-1	+1	0	0	+1	0	-1
IMP	0	0	0	-1	0	-1	+1	0	+1	+1	0	+1
FMP2	0	0	0	-1	0	-1	+1	0	+1	+1	0	+1
MCG	-1	-1	-1	-1	-1	-1	+1	+1	0	+1	0	-3
MCS	-1	-1	-1	-1	-1	-1	+1	+1	0	+1	0	-3

5. Final ranking and shortlisting

The final ranking of the 11 longlisted value chain cases, as presented in Table 15, was determined through a systemic evaluation based on four key criteria:

- Guiding social costs (GSC), comprising both the economy of the value chain owner(s) and the societal economy in the form of capitalised values of nutrient losses and GHG gas emissions (Foged et al., 2025).
- End-user perceptions
- Market potential
- Policy Environment

Each criterion was assessed by assigning a score to each case, where the best-performing case received a score of 1, the second-best 2, and so on. For value chains evaluated under two different baselines, average scores were calculated to ensure consistency.

To ensure a balanced representation across different waste sectors, the six highest-ranked value chains – those with the lowest total scores – were selected, with a preference for including two cases from each sector. Notably, the MML case was classified as an industrial case, given that industrial waste constitutes a significant portion of the organic materials that the digestate is based on, and because there otherwise alone would be one industrial case.

Table 15: Final ranking and shortlisting of the assessed value chains.

Value chain	Ranking (1 -highest to 11 – lowest)					Shortlist
	Guiding social costs	End-user perceptions	Market potentials	Policies	Total	
MTS1	2	6	10	8	26	
MML	8	10	1	1	20	2I
FCL	7	8	4	6	25	
FMS	9	8	1	1	19	2F
MCL	5	11	8	9	33	
MTS2	6	7	9	6	28	
FMP1	10	2	6	5	23	
IMP	4	1	5	1	11	1I
FMP2	11	3	1	1	16	1F
MCG	1	4	11	9	25	2M
MCS	3	4	7	9	23	1M

The shortlisted value chains exemplify innovative and promising approaches to enhancing nutrient recycling across various waste sectors:

1. **IMP - Fertiliser pellets from meat and bone meal:** The solution stands out as an exemplary solution for nutrient recycling through the sustainable use of meat and bone meal as fertiliser. Evaluated across multiple parameters, this approach showcases the most effective integration of waste materials into agricultural nutrient cycles.
2. **FMP2 - Manure pellets based on dried separation solids from digestate:** Effective recycling of the contained nutrients is based on mechanical separation. The nitrogen

rich separation liquids can be used locally in an efficient way, and the phosphorus rich solids be exported to other regions for avoiding local overdosing with P. Manure pellets are valued by end-users, especially organic farmers and those who want to improve the organic matter content of their soils. The disadvantage being that the plant available N in the solid fraction is lost via ammonia volatilisation during the drying process.

3. **FMS - Manure-based digestate separation technology:** The case illustrates that simple and cost-effective separation processes can significantly enhance the sustainable use of P in digestates and other liquid manures. This method has the potential to become a standard measure, improving nutrient management in agricultural practices.
4. **MML - Separation fractions from co-digested municipal and industrial wastes:** The case represents anaerobic digestion as a focal technology of increasing importance for handling of organic wastes, being converted to relatively uniform digestates, which is a good starting point for additional processing to recycle nutrients. The case highlights the perspectives for recycling of nutrients in various municipal and industrial wastes via co-digestion.
5. **MCS - Struvite fertiliser from activated sludge:** This value chain demonstrates a practical method for recovering nutrients from activated wastewater sludge. The resulting BBF is a relatively clean and concentrated product containing both N, P and Mg. While the nutrient release may be somewhat slow and the origin from wastewater could raise concerns, the approach offers a viable pathway for nutrient recovery.
6. **MCG - Urine-derived fertiliser:** The concept involves the production of fertiliser granules from human urine, addressing the current unsustainable handling of human waste. Urine contains a significant amount of N, and its recycling could potentially cover a considerable share of the N demand for crop production. Drawbacks may be the dependency on renovation of housing to use special toilets and establish separate collection systems.

6. Conclusions

BBFs hold significant potential for advancing nutrient recycling and promoting sustainable agriculture, but their widespread adoption is influenced by end-user perceptions, market potentials and policy challenges:

- **Farmer preferences and adoption barriers**

  Farmers exhibit a preference for BBFs that do not originate from wastewater, has a high plant availability of N and P nutrients, has a high nutrient content—particularly nitrogen, and can be field-spread and handled with conventional equipment. Farmers also see the fact that most BBFs contain organic matter as beneficial for improving soil structure fertility, which are critical factors for sustainable crop production. However, an overall criterion for crop farmers fertiliser preference is the price, which hampering the BBF market development since it is constrained by high production costs and the need for significant investments.

- **Market situation**

  The market potentials are in general high considering the availability of organic wastes, but limitations can be due to net costs of producing BBFs and national policies, such as whether wastewater sludge can be field spread for fertilisation without further processing. The price farmers are willing to pay for nutrients in BBFs is down to half of the price of nutrients in mineral fertilisers and given the nutrients in BBFs are more expensive to produce, as mentioned above, BBFs have extremely difficult market conditions.

- **Policy landscape**

  Current policy incentives for BBF production are overshadowed by regulatory barriers. Possibilities for offering financial incentives for increasing nutrient recycling as part of the Common Agricultural Policy (CAP) measures are given low or no prioritisation. Obtaining end-of-waste status is in some BSR countries rather complicated, not standardised, and the procedure not harmonised among BSR countries, complicating trade and business in the BSR with recycled fertiliser products, in specific those that are based on municipal and industrial wastes. Systems for rewarding those that contribute to increased nutrient recycling for the value of the ecosystem services they deliver to the society are not existing or complicated and associated with high transition costs. To foster the development and adoption of BBFs, it is imperative to streamline regulatory frameworks, enhance financial incentives, and promote research and development initiatives aimed at improving BBF quality and reducing production costs.

In summary, while the production of BBFs in general offers a promising avenue for sustainable nutrient management, realising their full potential necessitates concerted efforts to address economic constraints, develop fertiliser types that meets farmers demands, align regulatory frameworks, and support market development through targeted policies and stakeholder engagement. While guiding social costs for producing BBFs are higher than comparable prices for nutrients in mineral fertilisers, crop farmers have some reservations towards BBFs due to their technical qualities and are generally unwilling to pay the same for nutrients in BBFs as for nutrients in mineral fertilisers – see Figure 6.

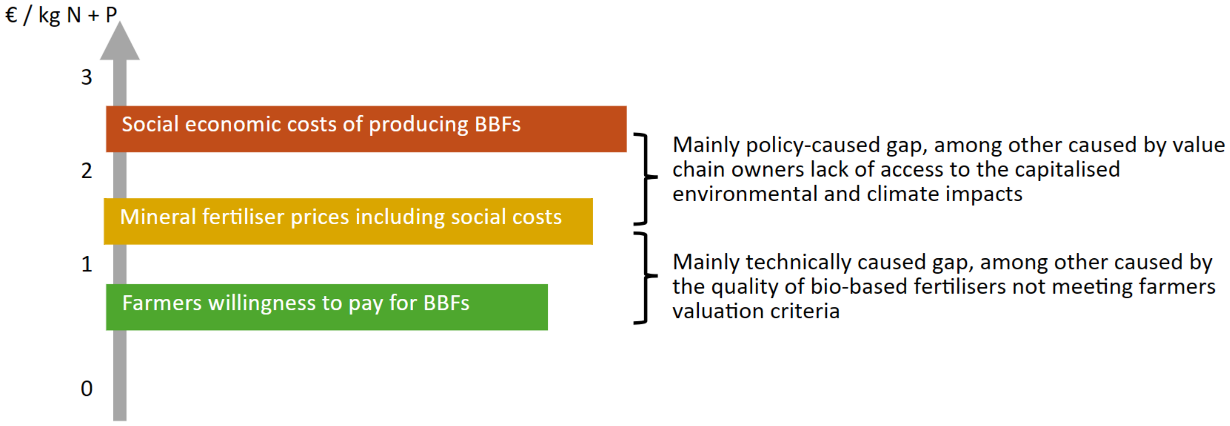

Figure 6: The general price dilemma of bio-based fertiliser shall be solved via technical development to make them better aligned with farmers preferences, and policy changes to support their production, at least for the environmental services they offer.

7. References

AgroTechnologyATLAS. 2025. Anaerobic treatment. https://www.agrotechnologyatlas.eu/techdescs?TechnologyId=601.

Al-Kazwini and Simhadri, 2025. Normal and Abnormal Urine Output and Interpretation. [Updated 2024 May 7]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK606132/

Aliahmad, A., Harder, R., Simha, P., Vinnerås, B., McConville, J. (2022). Knowledge evolution within human urine recycling technological innovation system (TIS): Focus on technologies for recovering plant-essential nutrients, Journal of Cleaner Production, 379, Part 2, 2022, https://doi.org/10.1016/j.jclepro.2022.134786.

Blomsterlandet, n.d. Accessed 2025-03-06. Gödsel för köksträdgården https://www.blomsterlandet.se/produkter/tillbehor/jord-godsel-naring/utomhus/godsel/godsel-for-kokstradgarden-hasselfors-garden-9405/?gad_source=1&gclid=CjwKCAiAiaC-BhBEEiwAjY99qJdxj5W7ku7kDKy6lul0uvGU6MUVNn4CYg4hX_Ba1TIMEXBDBGYqtBoCX6kQAvD_BwE

Businessanalitiq, 2025. Accessed 2025-03-21. Ammonium sulfate price index. https://businessanalytiq.com/procurementanalytics/index/ammonium-sulfate-index/

Chang, H., Zhao, Y., Zhao, S., Damgaard, A., Christensen, T.H. (2022). Review of inventory data for the thermal treatment of sewage sludge, Waste Management, Volume 146, Pages 106-118. https://doi.org/10.1016/j.wasman.2022.05.002

Chrispim, M. C., de M. de Souza, F., Scholz, M., & Nolasco, M. A. (2020). A Framework for Sustainable Planning and Decision-Making on Resource Recovery from Wastewater: Showcase for São Paulo Megacity. Water, 12(12), 3466. https://doi.org/10.3390/w12123466 Chrispim et al., 2022. https://www.mdpi.com/2073-4441/12/12/3466

Case, S.D.C., Oelofse, M., Hou, Y., Oenema, O., Jensen, L.S. (2017). Farmer perceptions and use of organic waste products as fertilisers – a survey study of potential benefits and barriers. Agric Sys. 151:84–95. https://doi.org/10.1016/j.agsy.2016.11.012

EBA, 2023. European Biogas Association Statistical Report 2023, Brussels, December 2023.

European Commission. 2002. EU Animal Byproducts Regulation (Regulation (EC) No 1774/2002) of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption. Official Journal, L273 (10/10/2002)

Ekman Burgman, L. (2022). What sewage sludge is and conflicts in Swedish circular economy policymaking, Environmental Sociology, DOI: 10.1080/23251042.2021.2021603

Eurostat, 2024, 21 May. Accessed 2025-03-27. Decline in EU livestock population in 2023. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240521-2

European Sustainable Phosphorus Platform (ESPP), Summary of ESPP webinar on Category 1 Animal By-Product Ash safety and prions, 22 May 2023. Available at: https://www.phosphorusplatform.eu.

Foged, Henning Lyngsø, Ida Sylwan, Priscila de Morais Lima. 2025. Identifying best practices and most innovative solutions for nutrient recycling and analysing them for their environmental, climate and economic performance. Report from CiNURGi project, Interreg BSR #C049.

Hermann, L., Hermann, R. (2021). Business case evaluation of five centralised anaerobic digesters applying nutrient recovery and reuse - A product from the H2020 project SYSTEMIC. Wageningen, Wageningen Environmental Research, The Netherlands. https://doi.org/10.18174/572618

Högstrand, S., Uzkurt Kaljunen, J., Kjerstadius, H., Al-Juboori, R., Jönsson, K., Mikola A., Peters G., Svanström, G. (2022). Rejektvattenrening med näringsåtervinning, SVU-rapport 2022-12 Svenskt Vatten Utveckling, Bromma, Sweden. https://vattenbokhandeln.svensktvatten.se/wp-content/uploads/2023/03/svu-rapport-2022-12.pdf

Jeng, A.S., Haraldsen, T.K., Grønlund, A., Pedersen, P.A. (2007). Meat and bone meal as nitrogen and phosphorus fertilizer to cereals and rye grass. In: Bationo, A., Waswa, B., Kihara, J., Kimetu, J. (eds) Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5760-1_21

Kominko, H., Gorazda, K., Wzorek, Z. (2024). Sewage sludge: A review of its risks and circular raw material potential, Journal of Water Process Engineering, Volume 63, https://doi.org/10.1016/j.jwpe.2024.105522

Kulikova, Y., Babich, O., Tsybina, A., Sukhikh, S., Mokrushin, I., Noskova, S., & Orlov, N. (2022). Feasibility of Thermal Utilization of Primary and Secondary Sludge from a Biological Wastewater Treatment Plant in Kaliningrad City. Energies, 15(15), 5639. https://doi.org/10.3390/en15155639

Lima, P. de M., Aronsson, H., Strand, L., Björs, M., & Pantelopoulos, A. (2024). Farmers' perceptions on organic fertilisers towards circularity – a case study in Sweden. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 74(1). https://doi.org/10.1080/09064710.2023.2290247

Lupton, S. (2017). Markets for waste and waste–derived fertilizers. An empirical survey, Journal of Rural Studies, Volume 55, Pages 83-99, https://doi.org/10.1016/j.jrurstud.2017.07.017

Moshkin, Egor, Sergio Garmendia Lemus, Lies Bamelis, Jeroen Buysse. 2023. Assessment of willingness-to-pay for bio-based fertilisers among farmers and agricultural advisors in the EU, Journal of Cleaner Production, Volume 414, 2023, 137548, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2023.137548.

Myllyviita, T., Rintamäki, H. (2018). In Finnish: Ruuantuottajien näkemyksiä ja kokemuksia kierrätyslannoitteiden käytöstä ja kehitystarpeista. Suomen ympäristökeskuksen raportteja 31/2018. Finnish Environment Institute, Helsinki. http://hdl.handle.net/10138/276964

Mozhiarasi, V., Natarajan, T.S. 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

Muys, M., Phukan, R., Brader, G., Samad, A., Moretti, M., Haiden, B., Pluchon, S., Roest, K., Vlaeminck, S.E., Spiller, M. (2021). A systematic comparison of commercially produced struvite: Quantities, qualities and soil-maize phosphorus availability, Science of The Total Environment, Volume 756, 143726, https://doi.org/10.1016/j.scitotenv.2020.143726

Pradhan, S. K., Mikola, A., Heinonen-Tanski, H., & Vahala, R. (2019). Recovery of nitrogen and phosphorus from human urine using membrane and precipitation process. Journal of Environmental Management, 247, 596-602. https://doi.org/10.1016/j.jenvman.2019.06.046

Regeringen. 2024. Aftale om et grønt Danmark (In English: Agreement on a green Denmark).

Reusch, T. B., Dierking, J., Andersson, H. C., Bonsdorff, E., Carstensen, J., Casini, M., ... & Zandersen, M. (2018). The Baltic Sea as a time machine for the future coastal ocean. Science advances, 4(5), eaar8195.

Schnell, M., Horst, T., Quicker, P. (2020). Thermal treatment of sewage sludge in Germany: A review, Journal of Environmental Management, Volume 263, 110367, https://doi.org/10.1016/j.jenvman.2020.110367

Simha, P., Vasiljev, A., Randall, D.G., Vinnerås, B. (2023). Factors influencing the recovery of organic nitrogen from fresh human urine dosed with organic/inorganic acids and concentrated by evaporation in ambient conditions, Science of The Total Environment, Volume 879, 163053, https://doi.org/10.1016/j.scitotenv.2023.163053

Statistics Poland (2022). Environment 2022 [Ochrona środowiska 2022]. Spatial and Environmental Surveys Department. https://stat.gov.pl/files/gfx/portalinformacyjny/en/defaultaktualnosci/3303/1/14/1/environment_2022.pdf

Statistics Sweden (2022a). Emissions to water and sewage sludge production 2022 [Utsläpp till vatten och slamproduktion 2022]. https://www.scb.se/contentassets/27596eabf4fd4f0da76a5eba3f512107/mi0106_2022a01_sm_misambr2501.pdf

Statistics Sweden (2022b). Use of fertilisers and animal manure in agriculture in 2021/22 [Gödselmedel i jordbruket 2021/22] https://www.scb.se/contentassets/6d115170251e40149815b2e101e5e396/mi1001_2021b22_sm_mi30sm2302.pdf

Tröster, M. F. (2023). Assessing the value of organic fertilizers from the perspective of EU farmers. Agriculture, 13(5), 1057. https://doi.org/10.3390/agriculture13051057

Ulinder, E., Cornelis, G., Lindhe, A., Sylwan, I., Dahlberg, A.K., Wiberg, K., Malm, M., Farquharson, L., Hübinette, M., Englund, M., Eveborn, D., Gustafsson, J.P., Löffler, P., Sindhöj, E. (2025). Filter media in soil treatment systems [Filtermaterial i markbaserade avloppsanläggningar], NATURVÅRDSVERKET RAPPORT 7160. Swedish EPA [Naturvårdsverket], Stockholm Sweden. https://www.naturvardsverket.se/48ffaa/globalassets/media/publikationer-pdf/7100/978-91-620-7160-8.pdf

Vinnerås, B., Palmquist, H., Balm´ er, P., J¨onsson, H., 2006. The Characteristics of Household Wastewater and Biodegradable Solid Waste—A Proposal for New Swedish Design Values. Urban Water Journal- URBAN WATER https://doi.org/J. 3. 3-11.10.1080/15730620600578629.3.

Yetilmezsoy, K., Ilhan, F., Kocak, E., & Akbin, H. M. (2017). Feasibility of struvite recovery process for fertilizer industry: A study of financial and economic analysis. Journal of cleaner production, 152, 88-102. https://doi.org/10.1016/j.jclepro.2017.03.106

Annex 1: Estimate of potentials of N and P in end-product

The estimated potentials of N and P were based on very rough estimates, given the estimate N and P in raw materials and the assumed losses during processing:

	MTS2	MCL	MTS1	MML	FCL	FMS	IMP	FMP1	FMP2	MCG	MCS
Rough estimate of potential of N in end-product	Close to zero	~22,000 ton (~86% of 25,000 ton)	~33,000 ton[a]	~0.83 million ton (no losses)	~2.1 million ton (no losses)	~0.83 million ton (no losses)	200 000,00	~0.82 million ton (0.8 % loss)	~0.71 million ton (15 % loss)	18–21% in end product; 250,000–290,000 ton [b]	50 000 (45% of 110 000)
Rough estimate of potential of P in end-product	~86,000 ton[c]	~880 ton (~10% of 8,800 ton)	~72,000 ton[a]	~0.15 million ton (no losses)	0.36 million ton (no losses)	0.15 million ton (no losses)	120 000,00	~0.15 million ton (no losses)	~0.15 million ton (no losses)	1.1–3.6 % in end product; 15,000–50,000 ton[b]	22,000 (50% of 44,000).

[a] Mass of sludge biochar assumed to be ~45% of sludge DM (Sylwan et al., 2023[4]; Vali et al., 2023[5]); concentration of N and P in sludge biochar assumed to be around 2-3% and 5-6% respectively (Zielínska et al., 2015)[6]).

[b] Protentional amount of urine in BSR is 46.5 billion litres, only 3% remains after drying (Simha et al., 2023), resulting in 1.395 billion litres DM.

[c] Assuming that 90% of P is in end-product after processing and if all sludge was incinerated and ash processed.

The scores assigned in Table 6 of the report were based on the following intervals:

Nutrient	Amount (ton)	Score
Nitrogen	from 0 to 100 000	-1
	from 100,000 to 500,000	0
	from 500,000 to several million ton	1

[4] Sylwan, I., Bergna, D., Runtti, H., Westholm, L. J., & Thorin, E. (2023). Primary and digested sludge-derived char as a Cd sorbent: feasibility of local utilisation. Water science and technology : a journal of the International Association on Water Pollution Research, 88(11), 2917–2930. https://doi.org/10.2166/WST.2023.356/1319508/WST2023356.PDF

[5] Vali, N., Combres, A., Hosseinian, A., & Pettersson, A. (2023). The Effect of the Elemental Composition of Municipal Sewage Sludge on the Phosphorus Recycling during Pyrolysis, with a Focus on the Char Chemistry—Modeling and Experiments. Separations 2023, 10, p. 31, 10(1), 31. https://doi.org/10.3390/SEPARATIONS10010031

[6] Zielińska, A., Oleszczuk, P., Charmas, B., Skubiszewska-Zięba, J., Pasieczna-Patkowska, S. (2015). Effect of sewage sludge properties on the biochar characteristic. Journal of Analytical and Applied Pyrolysis, 112, p. 201-213. https://doi.org/10.1016/j.jaap.2015.01.025

Nutrient	Amount (ton)	Score
Phosphorus	less than 1,000	-1
	from 1,000 to 100,000	0
	more than 100,000	1