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Identification and Assessment of Innovative Nutrient Recycling Solutions: Environmental, Climate, and Economic Performance

October, 2025

Henning Lyngsø Foged, Ida Sylwan, Priscila de Morais Lima

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.

Project homepage: https://interreg-baltic.eu/project/cinurgi
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Identification and Assessment of Innovative Nutrient Recycling Solutions: Environmental, Climate, and Economic Performance

Henning Lyngsø Foged[1*], Ida Sylwan[2], Priscila de Morais Lima[2]

[1] Organe Institute, Skødstrup, Denmark

[2] RISE Research Institutes of Sweden, Uppsala, Sweden

*Corresponding author: Henning Lyngsø Foged, Organe Institute, henning@organe.dk.

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 best practices and most innovative solutions for nutrient recycling - identifying relevant value chains and analysing them for their environmental, climate and economic performance. The findings and activities detailed herein contribute directly to CiNURGi's overarching goals by clarifying conditions for bio-based fertilisers contribution to policy targets of importance for the social economy.

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

BBFs	Bio-based fertilisers
BSR	Baltic Sea Region
CH4	Methane
CiNURGi	Circular Nutrients for a Sustainable Baltic Sea Region project
CO	Carbon Oxide
CO2	Carbon Dioxide
DERI	Direct Emission Reduction Impact
DM	Dry Matter
EC	European Commission
ETS	Emissions Trade System
EU	European Union
GHG	Greenhouse Gases
GSC	Guiding Social Cost
HELCOM	Helsinki Commission
IPCC	Intergovernmental Panel on Climate Change
MBM	Meat and Bone Meal
N	Nitrogen
N_2O	Dinitrogen Oxide (Nitrous Oxide)
NRI	Nutrient Recycling Impact
P	Phosphorus
RISE	Research Institutes of Sweden
SMEs	Small and Medium-sized Enterprises
SOUP	Single Operation Unit Process
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TRL	Technology Readiness Level

Executive Summary

The production of bio-based fertilisers (BBFs) offers the possibility for recycling of nitrogen (N) and phosphorus (P) in nutrient-containing organic wastes from agriculture, municipalities, and industries. BBFs can replace mineral fertilisers, reduce nutrient losses to the environment, lower greenhouse gas (GHG) emissions associated with mineral fertiliser production, and offer societal cost savings. Despite increasing interest, the production of BBFs remains limited, representing only a small fraction of the overall fertilizer market. Their production typically entails additional transportation and energy inputs and often involves the use of chemicals for N and P recovery. Moreover, both nutrient and carbon (C) recycling back into the food chain are frequently inefficient due to various technical and systemic constraints.

To address these challenges, this report identifies and analyses exemplary and innovative BBF value chains, covering waste collection, processing, and distribution, assessing their environmental, climate, and economic performance to highlight best practices and improvement opportunities.

An initial pool of 24 cases was compiled following an open call for BBF production value chains. Of these, 11 value chains were selected for detailed analysis. The remaining cases were excluded based on preliminary assessment, either because they did not focus on BBF production, lacked sufficient data for evaluation, or were at a low technological readiness level (TRL).

To evaluate the selected value chains, a tailored analytical framework - the Single Operation Unit Process (SOUP) method - was applied and adopted/developed to assess the environmental, climate and economic impacts in comparison with baseline scenarios.

The results showed a substantial variability in nutrient retention efficiency during processing, summarized in the "nutrient recycling impact" (NRI), with values ranging from -9% to 100%, where negative values indicate a decreased nutrient recycling compared to the baseline. The average NRI was calculated to 47%. The average "direct emission impact" (DEI) was 0.517 t CO_2-equivalents per 1,000 kg of N and P in the incoming organic waste, spanning from –13.2 to 28.4 t CO_2-equivalents. Where negative values indicate that the emissions decrease compared to the baseline. This variation reflects differences in organic matter (OM) and carbon (C) recycling potential, as well as transport and energy requirements across the value chains.

The overall economic impact of BBF value chains was assessed, including economy of the value chain owner(s) and the societal economy in the form of capitalised values of nutrient losses and GHG gas emissions. The socio-economic impact was summarized in the "guiding social cost" (GSC), in € per 1,000 kg of N and P in the incoming organic waste. The GSC averaged €-1,257, ranging widely from €-3,048 to €280, depending on the specific value chain configuration. The value chain costs, seen from a business perspective, were in average € 2.62 per kg N + P produced, with a variation from € 0.68 to € 4.94, thus clearly indicating that BBF production is in most cases unprofitable and not competitive with prices of nutrients in mineral fertilisers (assumed at € 1.08 per kg N and P in mineral fertilisers).

Finally, the nutrient concentration in BBFs compared with their raw organic feedstocks varied markedly. The highest observed increase reached 422-fold, while in some cases was no

concentration improvement was achieved, with nutrient levels in the BBFs equal to those in the input organic waste.

In conclusion, nutrient recycling through BBF production demonstrates moderately improved environmental, climate and economic performance compared to the baseline. However, the variability is considerable and dependent on the value chain configuration and local context. The market competitiveness of BBFs remains limited, while more than half of the analysed value chains are justified from a socio-economic perspective. BBF production proves most viable in cases where the alternative treatment of the nutrient-rich organic waste would be disposal without nutrient recycling such as incineration.

A comprehensive understanding of the full potential of BBF production, and of which value chains can be regarded as leading examples of best practice and innovation, requires further analysis of end-user perceptions, market dynamics, and policy implications. These aspects are examined in detail in a complementary report.

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-rich 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.

1.1. Scope of this study

This evaluation focuses on identifying and assessing innovative and effective nutrient recycling solutions emerging from farming, municipal, and industry processes. It aims to explore the market potential and barriers for these solutions to support the transition toward a circular economy for nutrients in the Baltic Sea Region.

CiNURGi focuses on the key nutrients nitrogen (N), phosphorus (P) and potassium (K) (see Figure 1), with a particular emphasis on N and P due to their contribution to eutrophication of waters, including the Baltic Sea. By addressing these nutrient flows, the project seeks to create a more sustainable and resource-efficient system for nutrient management in the region.

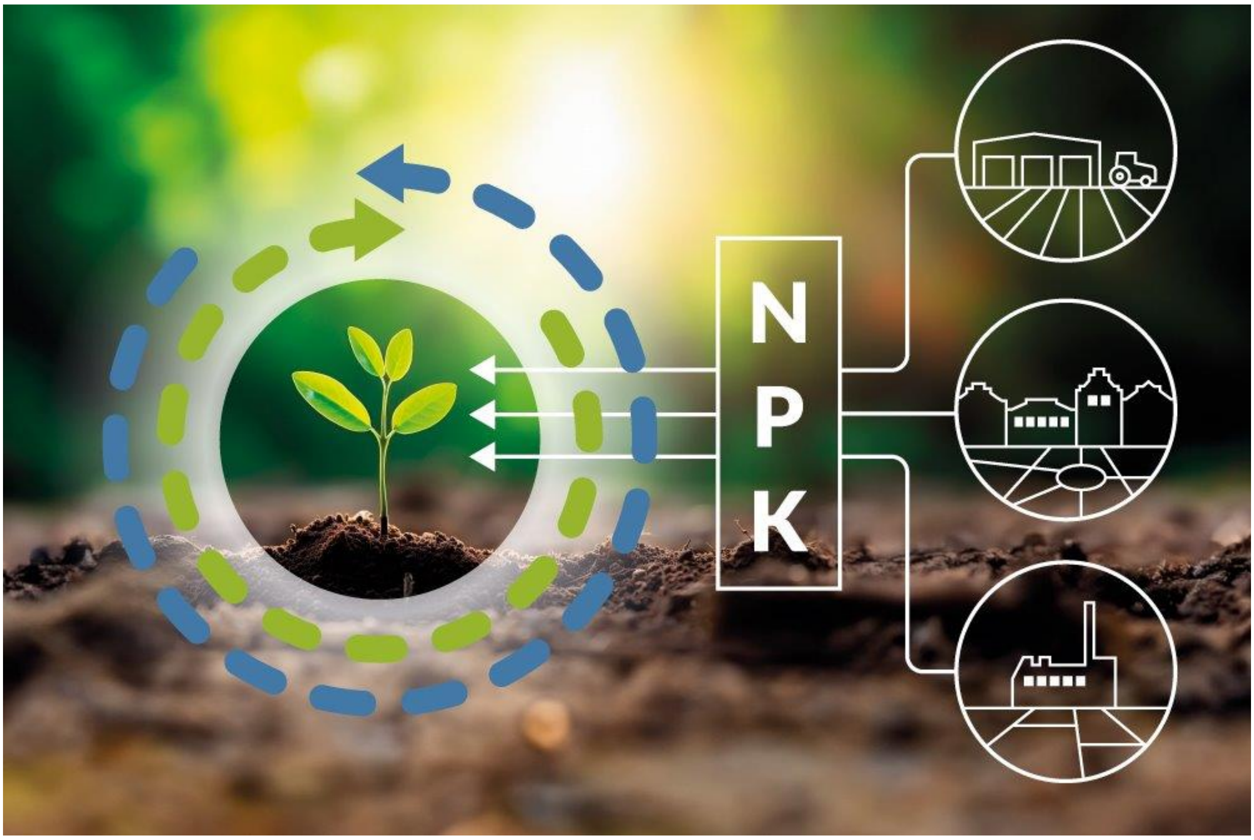

Figure 1. This CiNURGi profile illustration is clearly visualising the project focus on the plant macro nutrients N, P and K, the circularity and the scope being agricultural, municipal and industrial waste streams.

1.2. Regional nutrient imbalances and the need for redistribution of nutrients

Nutrient surpluses and deficits are unevenly distributed across countries and across the Baltic Sea Region. Areas with intensive livestock production often accumulate phosphorus (P) surpluses in soils, while other regions, dominated by crop production, face nutrient deficits. This imbalance results in inefficiencies in nutrient use, environmental risks, and continued reliance on imported mineral fertilisers.

One illustrative example is Denmark, where livestock-intensive western regions show a significant phosphorus surplus, while eastern regions experience deficits (Figure 2). Despite the potential for internal redistribution, phosphorus needs in the east have historically been met by fertiliser imports rather than by transferring surplus nutrients from the west. This situation highlights the logistical challenges of transporting untreated organic wastes, such as manure, across long distances and underscores the need for more concentrated, transportable nutrient recycling solutions like bio-based fertilisers.

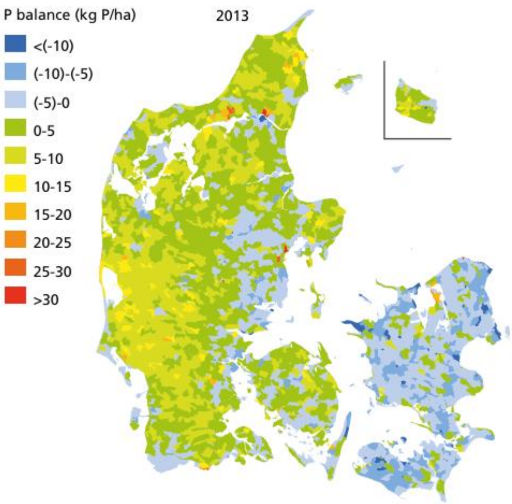

Figure 2. Phosphorus balance in Denmark 2013. (Source: Damgaard Poulsen et al. 2019).

A detailed quantification of nutrient surpluses, deficits, and biomass resource potentials across the Baltic Sea Region's NUTS2 statistical areas is provided in a separate forthcoming report (Loustarinen et al., 2025) from the CiNURGi project. The current report focuses instead on evaluating innovative nutrient recycling technologies and value chains that can help address these regional imbalances by improving nutrient recovery, efficiency, and circularity.

1.3. Objective of this technical report

This report presents how value chains for BBF production were identified, a method for analysing them for their environmental, climate and economic performance, and the results of these analyses.

2. Screening the market for relevant nutrient recycling value chains

This section describes the methodology used to identify, shortlist, and evaluate nutrient recycling value chains, based on their environmental, climate, economic, and market characteristics, as well as relevant policy conditions. The approach applied builds on the premise that analysing real-world examples of implemented nutrient recycling initiatives provides the most valuable insights into how market mechanisms function and how policies either facilitate or hinder their development.

Accordingly, a screening of the market for nutrient recycling solutions across agricultural, municipal and industrial waste streams was chosen as the starting point. Since nutrient recycling begins with nutrient-containing organic waste that undergoes a processing into a bio-based fertiliser, the search focused on value chains that included three key components: collection of the organic waste, processing into a fertiliser product, and distribution to end-users.

The systematic approach ensures that all key stages of nutrient recycling are considered, allowing for a comprehensive evaluation of market dynamics, technological innovations, and regulatory frameworks. Figure 3 illustrates the overall workflow applied to identify promising market opportunities and evaluate policies affecting nutrient recycling.

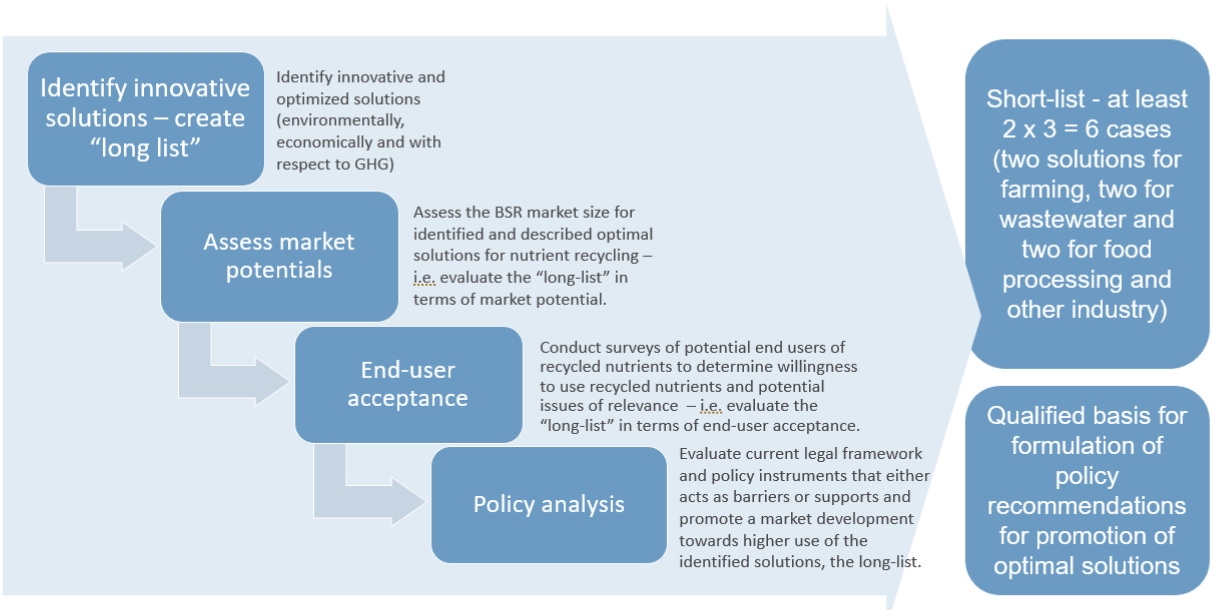

Figure 3. Overall workflow diagram applied to identify promising market opportunities and evaluate policies affecting nutrient recycling.

The process began with an open call to survey the market for best practices and innovative solutions that already exists or are nearing market maturity. A long list of prospective value chains was established based on assessments of overall relevance, assessed environmental and climate impacts, and estimated social costs. This report covers these assessments and their results.

The long-listed cases were then evaluated in greater detail for their market potential, end-user acceptance, and policy environment, identifying challenges and opportunities. Based on this comprehensive analysis, six high-potential value chains were selected for promotion and wider dissemination in the later phases of the CiNURGi project. This part is covered by a parallel report.

2.1. Call for identifying best value chains

The first step in the market screening process was the design and launch of a call to identify best practices and innovative solutions for nutrient recycling. The evaluation criteria and the specific type of information sought from respondents were carefully determined in a series of expert meetings. A total of 28 experts participated, representing all eight EU countries of the Baltic Sea Region. The collected information was structured around the following key aspects:

1. Identification of Respondents and Value Chain Owners

   Respondents were asked to provide details about themselves, the owners of the value chain, and, where applicable, the processing technology provider. In some cases, these roles were combined within the same company or individual.

   Clear identification was crucial for several reasons:

   - It enables the return to the respondent for additional details.
   - It makes project participants or other able to visit the value chain. The purpose was not at all to have responses in the form of generic processing technologies.

2. Descriptions of Value Chain Components

   Respondents were required to provide a detailed description of their value chain, including:

   - The type of nutrient-rich organic waste used as the starting point.
   - The processing steps involved.
   - The resulting bio-based fertiliser.

   These three elements are fundamental to nutrient recycling, and submissions that failed to clearly outline all three did not qualify for consideration.

3. Environmental Impact

   Since nutrient recycling only has value if it delivers a net environmental benefit, respondents were asked to quantify emissions and losses across the value chain.

   Typical losses can occur at various stages, such as N loss through volatilisation or by-products that are not recycled.

   A key environmental performance indicator was the nutrient mass balance, assessing the proportion of N and P retained in the final fertiliser product, being available for uptake by crops at some stage.

4. Climate Impact

   To ensure that nutrient recycling value chains contributing to reducing greenhouse gases (GHG) emissions, respondents were asked to assess:

   - Emissions reductions from replacing synthetic fertilisers.
   - GHG savings from avoided baseline waste management practices. This excludes emission from storages outside the defined scope.

- Energy consumption for processing and transport, which could negatively impact the climate balance.

5. Economic Viability

   The cost of operating the value chain was also assessed, as market potential is closely linked to economic feasibility. Solutions with a competitive cost structure relative to conventional fertilisers were prioritised.

2.1.1. Evaluation Approach and adjustments

The goal of the call was to collect responses enabling an objective ranking of nutrient recycling value chains, prioritising those delivering the highest environmental and climate impact per euro invested. However, obtaining comprehensive economic and environmental data from the respondents proved challenging, limiting the ability to apply a fully quantitative ranking approach.

2.1.2. Survey and outreach

To collect the necessary data, a questionnaire with 40 questions was developed and distributed via Google Forms – see https://forms.gle/ft1wJTBQLtMS9rsh7. The call for submissions was launched on 21 May 2024 through the CiNURGi project website - https://interreg-baltic.eu/project-posts/cinurgi/come-and-showcase-your-innovative-solutions-or-best-practices-for-nutrient-recycling/.

Additionally, the call was widely disseminated through multiple channels:

- LinkedIN - https://www.linkedin.com/showcase/cinurgi/.
- Partner websites, such as https://www.organe.dk/news_specific?id=50.
- Internal communications, including newsletters and Teams chat among project partners.

To support the announcement, informational and promotional materials were developed, including the official call announcement, presented in Figure 4.

A call for pioneers in nutrient recycling

Showcase your innovative solutions or best practices!

CiNURGi project launches a call and invites pioneers in nutrient recycling to step forward and share their success stories! Are you revolutionizing the way organic wastes are transformed into valuable fertilizers? Do you have a groundbreaking solution that reduces mineral fertilizer consumption while benefiting the environment? If so, we want to hear from you!

What is this about?

The call is open to all who are driving change in this vital field. We are seeking cases of value chains wherein nutrients from organic wastes in regions with nutrient surplus are processed into fertilizers that can be easily transported to regions lacking self-sufficiency in crop nutrients, or which in other ways contribute to nutrient recycling. We will evaluate proposed solutions through a weighted, combined assessment of the net costs for operating the value chains against their capitalised environmental and climatic net benefits, leading to a reduced mineral fertilizer consumption. Proposed cases should primarily be already commercialized but can also be in the later stages of development.

Ideally, proposed cases should be based on organic wastes from wastewater treatment, industrial processes, or farming.

Why should I take part?

The prioritized cases will not only gain recognition with peers and colleagues but also receive international visibility through CiNURGi communication channels. They will automatically become candidates for the "Best Nutrient Recycling Award," a competition intended to raise awareness among stakeholders about successful and cost-effective nutrient recycling solutions. The top-performing cases will be showcased at a European-level event planned for the end of the project.

How do I get in?

We invite anyone with a proposal to fill in and submit this easy template by **31 August 2024** – https://forms.gle/nR3cgQpCq6uSTeB5A

About the project?

CiNURGi website

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Figure 4. Call for best practices and most innovative solutions.

2.2. Managing the call process and overcoming participation barriers

In addition to promoting the call through public communication channels, the project team actively engaged in direct outreach. Project experts contacted companies, individuals, and organisations through personal communication to raise awareness and encourage participation. At the same time, the project team also received inbound inquiries from interested stakeholders seeking clarification regarding the call and the submission process.

Despite these efforts, several challenges emerged during the call process:

- **Complexity of the questionnaire:** Many respondents found the questionnaire difficult to complete in full, leading to the decision to make most responses optional in order to lower the threshold for participation.
- **Concerns over business confidentiality**: Some potential participants declined to respond, citing concerns that sharing details would compromise their business models.
- **Unclear incentives for participation**: Several stakeholders questioned the benefits of contributing, indicating a need for a clearer value proposition.
- **Low initial response rate**: The original deadline coincided with the summer holiday period, likely contributing to a limited number of responses.

To address these challenges, the project team implemented alternative information-gathering methods. In cases where written responses were not submitted, project experts conducted interviews with value chain owners and technology providers to collect the necessary data. Additionally, the deadline was extended by one month, moving the final submission date to the end of September 2024, to allow for broader participation.

2.3. Overview of collected value chains

Table 1 presents the 24 value chains identified through responses to the online submission form and through direct engagement by the team through interviews and outreach efforts. The value chainsTable 1 predominantly represent private-sector initiatives, with a strong participation from small and medium-sized enterprises (SMEs). To achieve a broad and representative sample of solutions across the Baltic Sea Region, the project team also conducted targeted outreach to approximately twice as many businesses as those formally submitting responses. This proactive engagement helped ensure that the collected value chains reflect a wide diversity of approaches to nutrient recycling from agricultural, municipal and industrial organic wastes.

Table 1. All identified value chains (in random order).

Title of value chains
Piloting dewatered sewage sludge to biochar through drying and pyrolysis
From digestate to separation liquids and solids via separation
From raw to acidified slurry via in-field acidification
Piloting growing media production based on any kind of organic wastes that is composted and inoculated with bacteria
From digestate to separation solids and liquids via settling and separation
Organic fertiliser pellets from meat and bone meal via mixing and pelletising

Title of value chains
Digestate and biomethane from a variety of food industry wastes and manure via anaerobic digestion
Piloting sludge reject water to ammonium sulphate solution through chemical fixation
Validating dewatered sewage sludge to P-rich end product via drying, mono-incineration and chemical extraction
Piloting digestate to organic fertiliser pellets through separation, drying and pelletising
Piloting production of separation liquids and compost from packaged food wastes and other organic wastes via anaerobic digestion
Captured ammonia nitrification system
From meat and bone meal to fertiliser pellet though mixing and pelletising
From municipal biowastes to digestate and compost via dry digestion and composting
From digestate to liquid and solid fertiliser via separation
From raking and pruning wastes to growing media via chopping
Sludge transfer service
From digestate to solid and liquid bio-fertiliser through phase separation
Developing a system for producing concentrated ammonium compounds and phosphorus rich soil improvers with chemical precipitation and membrane technology
From digestate to organic fertiliser pellets via separation, drying and pelletising
Testing urine to fertiliser granules through source separation, chemical fixation and drying
Prototyping activated sludge to struvite fertiliser through chemical processing
Local solution for handling biowastes
Digestate from livestock manures and other wastes via anaerobic digestion

2.3.1. Data quality challenges

While the call successfully identified relevant value chains, the overall quality of the collected data posed difficulties for conducting a fully structured ranking based on environmental and economic performance. Several key challenges emerged:

- **Misinterpretation of the Technology Readiness Level (TRL)**: several respondents misunderstood the TRL classification, leading to inconsistent reporting of the maturity of their solutions.
- **Lack of economic data**: Many businesses declined to disclose pricing and economic details, citing concerns over business confidentiality. This reluctance persisted despite the confidentiality assurances in the questionnaire introduction, which included an option to sign an NDA (Non-Disclosure Agreement) and a guarantee that no information would be published without prior written approval.
- **Limited credibility of environmental and climate impact data**: Submissions on environmental and climate performance were often incomplete or lacked sufficient detail to support a meaningful evaluation.

- **Unclear value chain descriptions**: several submissions did not clearly specify the type of organic waste as the starting material, nor did they provide adequate information about the characteristics and quality of the resulting bio-based fertilisers.

These limitations reduced the ability to apply a fully quantitative assessment across all cases and necessitated the use of complementary expert judgment in the evaluation process.

2.3.2. Outcomes of the call and adaptations to the evaluation approach

Whie the call successfully identified a significant number of relevant cases; the limited availability of detailed and structured data made it unfeasible to conduct a fully objective ranking of value chains based on environmental and climate impact per unit cost. Nevertheless, the call generated valuable results. A total of 24 cases were identified (**Fel! Hittar inte referenskälla.**), involving:

- Value chain owners, technology providers and key stakeholders engaged in nutrient recycling.
- Actors willing to cooperate with CiNURGi to advance nutrient recycling solutions.
- Value chains based on nutrient-rich organic waste streams from agriculture, municipal and industry.
- These cases provide a strong foundation for further analysis of end-user perceptions, market potential, and policy challenges or opportunities, as outlined in the methodology framework (Figure 3).

2.3.3. Transferring value chain key information to a standardised poster format

Key information about each value chain was summarised in a standardised poster format (see Annex A and C) to enable a structured and transparent review process. To become familiar with the cases, two online meetings, each lasting three hours, were organised for presenting, discussing, and commenting each case.

The initial presentation of the cases made it clear that a further refining of the quality and consistency of the key information displayed in the posters was necessary for making an evaluation of the cases on an equal basis possible.

To enhance consistency and quality of the posters, the following improvements were implemented:

i. **Scope alignment** – Posters were revised to focus exclusively on the value chain, clearly describing the nutrient-containing organic waste as the starting point.

ii. **TRL corrections** – the Technology Readiness Level (TRL) classification was reviewed and adjusted to align with EU's official definitions introduced in 2012 for Horizon projects (see EU TRL reference at https://shorturl.at/qIWZ6).

iii. **Standardised title format** – All poste titles were reformulated to follow the structure:

"From [nutrient containing organic waste] to [biobased fertiliser] via [main process]"

iv. **Photo validation** – All images were reviewed to ensure relevance to the value chain and verified for permission of use.

v. **Fertiliser presentation** – Efforts were made to include photographs of the final bio-based fertiliser products, along with a chemical composition declaration (Dry Matter, Total Nitrogen, Ammonium Nitrogen, Phosphorus content and density) where available.

vi. **Baseline description review** – Baseline scenarios were reassessed, particularly for cases where the original scope had been revised.

vii. **Text formatting** – text was standardized within allocated spaces without altering the font size. Uncommon abbreviations or technical codes were spelled out, explained, or removed for clarity.

viii. **File format consistency** – all posters were submitted in editable .pptx format to allow further refinements.

In addition to these improvements, enhancements were made to the environmental, climate and social costs impact assessments, as detailed in section 3.

2.3.4. Longlisting of value chains

Following the refinements described in section 2.3.3, and based on preliminary assessments of the environmental, climate and social costs impacts, a final longlisting of 12 value chains was established.

The additional information obtained through poster improvements and direct engagement significantly enhanced the quality of the data for assessing the value chains. Clarifications regarding the scopes and baseline conditions, as well as better specifications of the type and chemical composition of influent organic wastes and resulting bio-based fertiliser products and byproducts, provided a much stronger basis for assessment.

A final long listing decision was made during an expert meeting on 27 January 2025. It is noteworthy that some cases that had initially ranked highly during the subjective ranking were excluded after a more rigorous and objective reassessment. Key reasons for exclusion included:

- **Low TRL**: Solutions were not sufficiently advanced for the project focus, which targeted technologies already commercialised or in the later stages of development.
- **Lack of data sharing**: Some actors were unwilling to provide the information necessary to assess environmental and climate impacts.
- **Scope misalignment**: Some cases did not meet the call criteria, as they did not describe a full value chain converting nutrient containing organic wastes into bio-based fertilisers.

Furthermore, the longlist was later revised to exclude the value chain “From digestate to solid and liquid bio-fertiliser through phase separation”- It was clarified that this value chain was not a commercialised solution but a discontinued pilot initiative. Its removal did not significantly affect the breadth of the longlist, as similar technologies were represented in other shortlisted cases.

The final longlist of 11 value chains is presented in Table 2. The methods used for the environmental, climate and social costs impact assessments are described in Section 3.

Table 2. Longlisted value chains, the title and the value chain code. Listed in random 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).

Details of the longlisted cases are presented in a uniform poster format in Annex 2.

3. Method for assessing the environmental, climate and overall economic impacts of the value chains

The value chains submitted in response to the call for best practices and innovative solutions for recycling of nutrients were evaluated based on their direct environmental, climate and overall economic impact.

To ensure a consistency and objectivity, a standardised evaluation framework was developed. This framework incorporates key performance indicators relevant to nutrient recycling and enables a comparative ranking of the value chains on an equal basis, independent of their country of origin.

3.1. Environmental impact assessment

The primary objective of the environmental assessment is to assess the value chains' direct nutrient recycling impact (NRI), expressed as a percentage (%) of nutrients effectively recycled, compared to a baseline situation.

The NRI is defined as the incremental proportion of N and P in the input organic waste stream that ultimately becomes available for plant uptake as nutrients in crops. During the conversion process, some nutrients may be lost to the environment through gaseous emissions, runoff, or retention in by-products, reducing the efficiency of nutrient recovery.

The assessments rely on scientific references and established models to estimate the conversion efficiency of N and P into bio-based fertilisers (BBFs). The evaluation primarily considers the nutrient content of the final product, ensuring that only the nutrients retained in a crop-available form are included in the recycling potential. Nutrients delivered in chemically inert forms were excluded from the assessment. However, the method does not account for the timing of nutrient release (e.g. water-soluble vs slow-release forms).

Where the process generates by-products containing N and P that are similarly being made available for plant uptake, these are also considered part of the total recycling impact. Consequently, the nutrient recycling impact (NRI) is defined as the percentage (%) of nutrients found in the final BBF product and by-products in relation to that recycled in the baseline and that found in the input organic waste, as defined in Equation 1.

$$NRI(\%)=-(\Delta N_{BBF} + \Delta P_{BBF}) / 1,000 \times 100$$ **Equation 1**

Where the ΔN_{BBF} and ΔP_{BBF} is the amount of N and P respectively that is recycled as bio-based fertilisers (BBF) per functional unit (fu), i.e. 1,000 kg of N and P in the influent organic waste, compared to the baseline scenario.

Accurate calculation of the NRI requires knowledge of the total quantity of BBF produced from 1,000 kg of input N and P, along with their chemical composition (N, P, and Dry Matter). This information was primarily obtained through consultations with the technology providers. Where direct data were unavailable, standard reference values were used.

Additionally, the quantity and composition of the influent material (the original nutrient-containing organic waste) had to be identified. In cases where this information was not provided by the technology provider, standard reference values were used as substitutes.

A recognised limitation of the NRI method is that it focuses solely on N and P. Other important factors, such as additional plant nutrients (e.g., potassium and magnesium) or potential environmental hazards (e.g., heavy metals and organic pollutants), are not captured. A more comprehensive future analysis could expand the scope to include these parameters, providing a more holistic evaluation of the environmental impact of nutrient recycling solutions.

3.2. Climate impact assessment

The climate impact of each value chain was evaluated based on its Direct Emission Impact (DEI) in terms of greenhouse gas (GHG) emissions. The DEI assessment considered four main parameters:

- **<u>Saved emissions from mineral fertiliser replacement</u>:** The replacement of mineral fertilisers results in avoided GHG emissions from production and transport of these, calculated as:

  ΔGHG_m, $kgCO_2eq/fu = \Delta N_{BBF} \times F_N + \Delta P_{BBF} \times F_P$ **Equation 2**

  Where ΔN_{BBF} and ΔP_{BBF} is given by Equation 1, and $F_{N/P}$ are the emission factors for mineral fertilisers (kg CO_2eq per kg of N and P, respectively). The emission factors used were 3.40 kg CO_2eq per kg N and 2.75 kg CO_2eq per kg P, based on median values of examples provided by Havukainen et al. (2018).

- **<u>Emissions from transport</u>:** Transport-related emissions were calculated for: i) collection of influent organic waste material, ii) transport to the processing site, and iii) Distribution of BBFs to end-users. In many cases, collection of wastes and delivery to the processing site is done in one operation, and in all cases of the same amounts of wastes. Transport emissions were based on ton-kilometres (tkm) and calculated as:

  ΔGHG_t, $kgCO_2eq/fu = (\Delta tk_{INPUT} + \Delta tk_{BBF}) \times F_t$ **Equation 3**

  Where Ft is emission factors for truck transport of 1 ton of material 1 km, set at 0.111 kg CO_2eq per tkm (Ragon & Rodríguez, 2021; truck type RD9). Δtk_{INPUT} and Δtk_{BBF} refer to transport distances for collection and distribution stages, respectively, of amounts (ton material) per functional unit, with the Δ-sign indicating the change from the baseline scenario.

  Energy use during the collection and distribution stages (other than transport) was considered negligible for all cases.

- **<u>Emissions from energy consumption</u>:** Processing organic wastes into BBFs consumes energy, which contributes to GHG emissions. This impact was calculated as:

  ΔGHG_p, $kgCO_2eq/fu = \Delta pE \times F_E$ **Equation 4**

  Where ΔpE is the change of electricity consumed per functional unit during processing (kWh), in relation to the baseline scenario. F_E is the climate footprint of electricity, set at 0.255 kg CO_2eq per kWh (Jones, 2023).

- **<u>Emissions related to organic matter loss</u>:** Processing methods that involves oxidation of organic matter leads to carbon losses, which are assumed to be emitted as CO_2. In reality, losses may also include CO, CH_4, N_2O, and other compounds, thus, this simplification introduces some uncertainty. The emissions from organic matter loss were calculated as:

$$\Delta GHG_o\text{, kg } CO_2eq/fu = m_{DM} \times f_{OM} \times F_C \times \Delta C \times \frac{44}{12} \times 1{,}000$$ **Equation 5**

Where m_{DM} is the mass in tonnes of influent dry matter (DM) per functional unit, f_{OM} is the share of organic matter (OM) in the dry matter, which for many organic wastes would be around 0.7, equal to 70% OM of dry matter DM. F_C is the carbon (C) fraction of organic matter (OM) in the organic waste, and for organic wastes there can in many cases be assumed 57% C of OM, equal to 40% C of DM. ΔC is the change in loss of carbon (C) in relation to the baseline scenario. 44/12 is the stoichiometric conversion factor from C to CO_2eq. Multiplication with 1,000 is done to convert the input factors in ton to the result in kg.

In conclusion, the total DEI was calculated as follows:

$$DEI\text{, kg } CO_2eq/fu = -\Delta GHG_m + \Delta GHG_t + \Delta GHG_p + \Delta GHG_o$$ **Equation 6**

Where $-\Delta GHG_m$ is the emissions from mineral fertiliser substitution, ΔGHG_t is the emissions from transport, ΔGHG_p is emissions from energy consumption during processing, ΔGHG_o emissions from organic matter loss, and Δ in all cases indicating the change from the baseline scenario. A positive DEI value indicates a net increase in GHG emissions compared to the baseline scenario.

3.3. Assessment of socio-economic impact and market competitiveness

The overall economic impact of value chains for BBF production is called Guiding Social Costs (GSC), indicating it comprises 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. The GSC, € per kg nutrient (N and P) recycled, comprises four elements:

- **Nutrient losses (N and P)**: Valued using data from the *Environmental Prices Handbook for EU28*, assigning monetary costs to nutrient emissions linked to environmental degradation.
- **GHG emissions (CO_2eq)**: Valued based on the prevailing prices under the *EU Emissions Trade System (ETS)*, representing the cost of emission or the value of avoided emissions.
- **Value chain costs:** The value chain owners net economy, including operational and fixed costs, which is a net cost since it also includes possible income in the form of gate fees and subsidies.
- **Market value**: A domestic production of fertiliser has a socio-economic value, since it means improved trade balance and better employment. The value is estimated at half of the long-term market price for N and P nutrients in mineral fertilisers, whereas the socio-economic value may be lower for countries with own mineral fertiliser production and vice-versa.

The net value chain costs of a nutrient recycling value chain involve the following elements:

- **Investment costs**: Machinery, land, and infrastructure.

- **Operational costs**: Transport, handling, storage, processing, packaging (including labour, consumables, and energy).
- **Administrative costs**: Compliance, certification, and overhead.
- **Revenue sources**: Government subsidies, and gate fees from input material suppliers.

Due to business confidentiality, detailed cost data from operators were not available. Therefore, a generalised cost model was applied, estimating total costs ranges based on the literature. As with environmental and climate assessments, comparisons were made relative to baseline scenarios, with the economic impact calculated as the difference in total societal costs.

Given the diversity of technologies, value chain costs were classified into four categories:

- **No-cost processing** (0 €/ton organic matter): Applied to baseline scenarios where no additional treatment is required (e.g., direct use of digestate).
- **Low-cost processing** (100 €/ton organic matter): Includes simpler processes such as separation, mixing, pelletising, or acidification.
- **Medium-cost processing** (200 €/ton organic matter): Includes moderately complex operations such as separation combined with thermal drying and pelletising.
- **High-cost processing** (300 €/ton organic matter): Applies to advanced and multi-step systems such as thermal drying followed by pyrolysis, or intensive chemical treatments.

Thus, the value chain cost is especially associated with processing, and it was found relevant to do the estimation on an organic matter basis, since the mass of one functional unit of influent material varied substantially from 57 to 1,518 tonnes for the AquaGreen and Soepenberg cases, respectively, whereas the processing costs mainly relates to the content of organic matter, which is a main subject of processing for BBF production.

Calculation of Guiding Social Cost (GSC)

Based on these assumptions, the GSC (€ per kg nutrients replacing mineral fertiliser) indicator is calculated as:

$$\text{GSC, € per fu} = NL_{N+P,\ fu} + GHG_{N+P,\ fu} + P_{N+P,\ fu} - (V_{N,\ BBF} + V_{P,\ BBF}) \qquad \textbf{Equation 7}$$

Where:

- $NL_{N+P,\ fu}$ (€ per functional unit) is the social cost of nutrient losses which occur in the value chain/ during processing, assumed as $F_N \times \Delta N_{BBF} + F_P \times \Delta P_{BBF}$, where F_N and F_P are cost factors for losses of N and P, assumed as €3.11 and €1.86 per kg N and P, respectively (de Bruyn et al., 2018). The parameters ΔN_{BBF} and ΔP_{BBF} are according to Equation 1.
- $GHG_{N+P,\ fu}$ (€ per functional unit) is the social cost of GHG emissions, assumed as $DEI/1000 \times F_{GHG}$, where F_{GHG} is the price for EU Carbon Permits; assumed at €76.92 per tonne CO_2-eq, based on EMBER (2024).
- $P_{N+P,\ fu}$ (€ per functional unit) is the processing cost calculated as $m_{OM} \times \Delta C$, where m_{OM} is ton organic matter per functional unit and ΔC is the change from the baseline of the value chain cost factor as described above; assumed based on the complexity of processing: no-cost / low-cost / medium cost / high cost.
- $V_{N,\ BBF}$ and $V_{P,\ BBF}$ is the socio-economic value, estimated as half of the long term market value (MV) in Euro of N and P, assumed as $V_{N,\ BBF} = -\Delta N_{BBF} \times MV_{N,BBF}$ and

$V_{P,\,BBF} = -\,\Delta P_{BBF} \times MV_P$ where $MV_{N,BBF}$ is assumed to be €0.5 per kg N and $MV_{P,BBF}$ €0.75 per kg P based on a long term perspective on mineral fertiliser market prices.

As with environmental and climate assessments, comparisons are made relative to baseline scenarios, i.e., the economic impact is calculated based on relative difference compared to the baseline.

The GSC in Equation 7 is expressed in € per fu and is as such explaining the cost for the society of producing BBFs out of organic wastes that contain 1,000 kg N and P. Another perspective, considering the social costs per kg N and P in BBFs, compared to the baseline, does not give sense in all cases, since four out of 11 value chains has zero or negative nutrient recycling impact, wherefore the GSC per kg N and P is infinite.

Market competitiveness

In the perspective of the businesses that operate the value chains from organic wastes to BBFs, the economy is simpler; and can be represented as the value chain (net) costs in relation to the amount of N and P nutrient that can be marketed.

For value chain owners, baseline scenarios primarily provide contextual information on existing waste management costs, while investment decisions are driven by the incremental costs and revenues associated with implemented BBF production.

The market competitiveness of BBF production is calculated as:

P, € per kg N and P in BBF = $BC_{BBF,\,fu} \,/\, NP_{BBF}$ **Equation 8**

Where:

- $BC_{BBF,\,fu}$ (€ per functional unit) is calculated as the value chain cost (C) multiplied by the amount of organic matter per fu (m_{OM}). Without subtracting the assumed value chain costs from the baseline.
- NP_{BBF} is the amount of N and P per functional unit in the produced BBF.

Interpretation of the Economic Assessment

These economic assessments should be interpreted as generalised evaluations rather than direct reflections of specific companies or businesses operating the value chains. They provide:

- A comparative understanding of the economics of BBF production.
- Insights into cost variability across waste types and processing intensities.
- A framework for considering the societal value and environmental services associated with nutrient recycling.

By applying this structured approach, the analysis systematically evaluates the economic feasibility of nutrient recycling solutions, while considering both market conditions and broader societal benefits.

3.4. Scope and limitations of the assessments

The aim of this assessment is to provide a simplified, yet structured evaluation of the environmental. climate, and economic impacts associated with operating the nutrient recycling value chains. Due to the inherent complexity and variability of nutrient recycling processes, the calculated cost per functional unit and per kilogram of N and P in the resulting BBF should be interpreted as indicative rather than precise economic values. Actual financial performance may vary considerably across individual value chains.

The assessment focuses on the amount of C, N, and P recycled to agricultural fields, in forms that are either immediately plant-available or gradually released over time. For the sake of standardisation and comparability across diverse value chains, several important aspects were intentionally excluded:

- **Nutrient availability dynamics**: The analysis does not account for the timing of the nutrient release after application. While BBFs are commonly evaluated based on the first-year availability, especially for N, P release can occur over multiple growing seasons and is highly dependent on soil conditions (e.g., pH, texture). Studies such as Rudbæk et al. (2018) highlight these complexities.
- **Spreading and logistical impacts**: Practical benefits such as reduced soil compaction or improved handling efficiency when applying concentrated BBFs versus untreated organic waste were not included.

Despite these simplifications, the economic assessment provides a general understanding of the economic landscape for BBF production, illustrating variability across waste types, processing technologies, and value chain configurations.

Functional unit and system boundary

The functional unit used for the assessments is 1,000 kg N + P (in elemental form) present in the nutrient-containing organic waste input to each value chain.

The system boundary for the assessment is defined as the Single Operation Unit Process (SOUP) concept, adapted from Fazio et al. (2020). The SOUP framework encompasses the core steps directly contributing to BBR production:

1. **Collection** of nutrient-rich organic residues.
2. **Processing** through mechanical, biological, chemical, or thermal methods.
3. **Distribution** of BBFs to end-users (crop producers), where the product substitutes for conventional mineral fertilisers.

The SOUP is understood as a "process step that cannot be usefully further subdivided in terms of data collection for delivering the functional unit or reference flow" (Fazio et al., 2020), ensuring data consistency and comparability across diverse technical configurations (Figure 5).

The SOUP methodology isolates the production of BBFs from broader facility operations, ensuring that only processes with a primary nutrient recycling function are assessed. For example, in a biogas plant, digestate management intended for BBR production would be considered a SOUP, while broader energy generation processes would not. SOUPs in which BBF production is only a secondary output were excluded from the assessment, as their nutrient recycling impacts cannot be meaningfully separated from other operational objectives. This approach provides a focused and purpose-driven analysis of nutrient recycling solutions.

Each value chain is evaluated relative to a baseline scenario, representing the conventional waste management practices that would be applied if the BBF-producing value chain were not in place.

The NRI, DEI and social cost indicators are thus calculated strictly based on the defined SOUP, independent of broader system impacts.

Due to limited access to detailed operational data, particularly regarding environmental and economic performance, the assessments rely heavily on standard reference values and literature-derived assumptions. Care was taken to cite all sources for transparency and replicability. Nevertheless, the results should be viewed as indicative, providing comparative insights rather than precise measurements.

The methodological approach adopted in this assessment enables a structured, comparable, and practical evaluation of BBF-focused nutrient recycling value chains. It supports the identification of best practices, highlights market and policy barriers, and strengthens understanding of the opportunities and challenges for scaling sustainable nutrient recycling solutions.

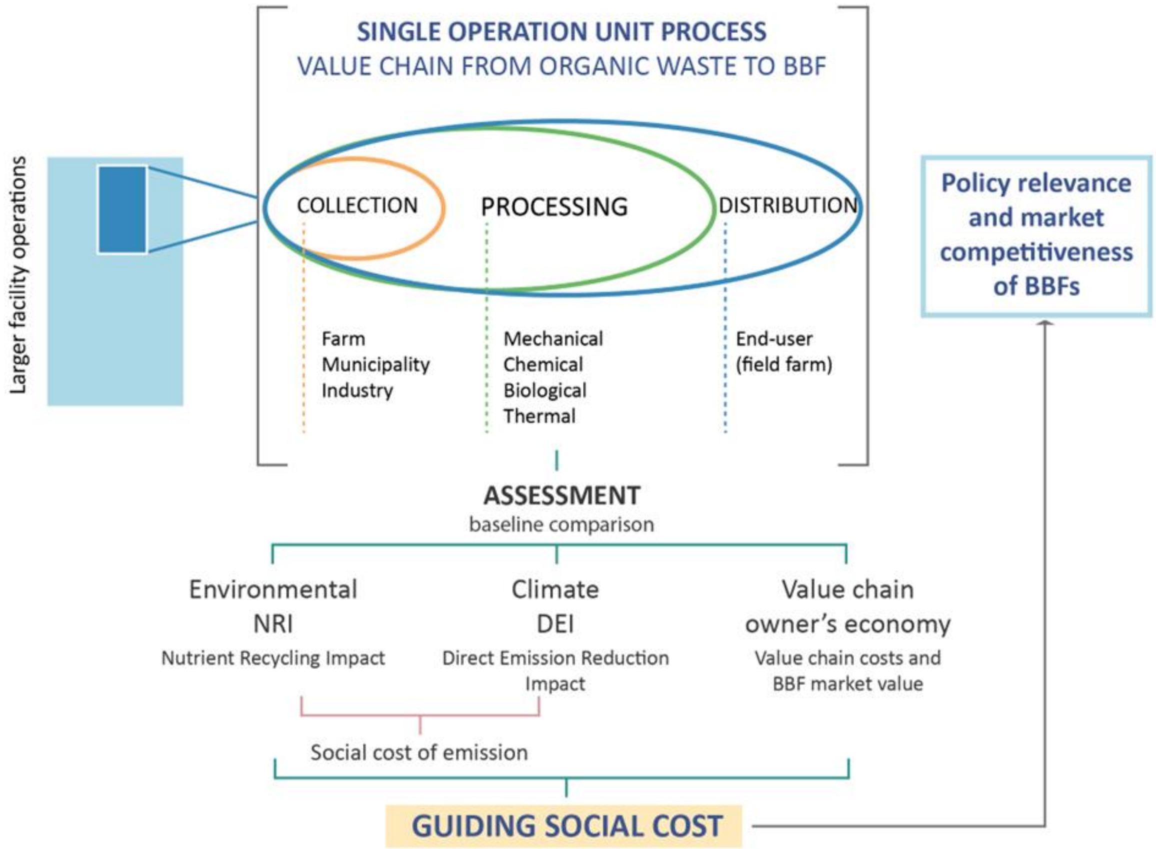

Figure 5. Illustration of single operation unit process (SOUP). Source: Based on Fazio et al. (2020).

4. Results of the assessments

In the following sections, the results of the socio-economic and the market economic impact assessments of the evaluated value chains are presented.

4.1. Environmental, climate and overall socio-economic impacts

Table 3 presents the results of the environmental, climate, and overall socio-economic assessments conducted using the methodologies described in the preceding sections, in specific results of equations 1-7.

Table 3. Results of environmental, climate and economic assessments. The assessments are limited to direct impacts related to nutrient recycling and specific baselines. All values are per functional unit, 1,000 kg N and P in influent organic wastes.

Waste sector	TRL	Case	Baseline	Nutrient concentration impact[1]	Net losses, kg			DEI[2], kg CO_2eq	NRI[3] (%)	Net value chain costs, €	Guiding social cost, €
					OM	N	P				
I	7	MCG - From human urine to fertiliser granules via source separation, chemical fixation and drying	Conventional wastewater treatment	21	-1,956	-950	-50	-4,781	100	378	-3,550
H	0	MTS1 - From dewatered sludge to biochar via drying and pyrolysis	Incineration with landfilling of ash	6	-2,850	-497	-279	-13,226	78	1,000	-2,539
H	8	MCS - From activated wastewater sludge to struvite fertiliser via chemical processing	Incineration with ash to landfill	422	-1,264	-564	-436	-6,976	100	1,052	-2,658
H	9	IMP - From meat and bone meal to fertiliser pellets via mixing and pelletising	Incineration with ash to landfill	1	-15,917	-700	-300	28,434	100	0	-1,122
F	7	MCL - From wastewater sludge reject water to ammonia sulphate solution via chemical fixation	Conventional wastewater treatment	15	0	-745	-255	-4,703	100	3,208	-509

[1] Weight of BBF / weight of influent material

[2] Direct Emission Impact

[3] Nutrient Recycling Impact

Waste sector	TRL	Case	Baseline	Nutrient concentration impact[1]	Net losses, kg			DEI[2], kg CO_2eq	NRI[3] (%)	Net value chain costs, €	Guiding social cost, €
					OM	N	P				
H	7	MTS2 - From dewatered sewage sludge to calcium phosphate via drying, mono-incineration and chemical extraction	Incineration with landfilling of ash	27	0	0	-386	388	39	1,000	23
H	9	FCL - From liquid manure to acidified slurry via in-field acidification	No further processing	1	270	-68	0	758	7	675	489
H/I	9	MML - From municipal and industry-based digestate to liquids and solids via separation	No further processing	1	0	0	0	21	0	1,000	1,002
F	9	FMS - From manure digestate to liquids and solids via settling and separation	No further processing	1	0	0	0	2,313	0	1,222	1,400
F/H/I	9	FMP1 - From digestate to manure granules via drying and granulation	No further processing	16	0	7	0	1,690	-1	1,242	1,398
F/H	9	FMP2 - From plant based digestate to organic fertiliser pellets via separation, drying and pelletising	No further processing	15	0	90	0	1,763	-9	1,027	1,487
Average				**48**	**-1,974**	**-312**	**-155**	**517**	**47**	**1,073**	**-416**

Table 3 illustrates substantial variation in performance knowing all value chains are assessed relative to their baseline scenario:

- Nutrient concentration ratios range from 1 to 422, with an average of 48, indicating large differences in the degree of nutrient concentration achieved during processing.
- Organic matter (OM) losses average -1,974 kg per functional unit, ranging from -15,917 to +270 kg.
- The average direct emission impact (DEI) was 0.517 t CO_2eq per functional unit, with values ranging from -13.2 to 28.4 t CO_2eq per functional unit.
- The nutrient recycling impact averaged 47%, ranging from -9 to 100%.
- Incremental value chain costs averaged €1,073 per functional unit.
- Guiding social costs (GSC) ranged from €-3,550 to €1,487 per functional unit, with an average of €-416.

To further explain the drivers behind the GSC, Table 4 presents its decomposition into social costs of nutrient losses, social costs of greenhouse gas emissions, estimated value chain costs, and the social value of BBF production.

Table 4. The overall Guiding Social Cost (GSC) per functional unit, and its elements of capitalised social costs of nutrient losses and greenhouse gas emissions, estimated value chain costs, and the social value of BBF production, in all cases expressed in € per functional unit in relation to the baseline scenario.

Case	Baseline	GSC in total (excl. value chain costs)	Social costs of nutrient losses	Social costs of GHG emissions	Estimated value chain costs	Social value of BBF production
		€ per functional unit				
MCG - From human urine to fertiliser granules via source separation, chemical fixation and drying	Conventional wastewater treatment	-3,550 (-3,928)	-3,048	-368	378	512.4
MTS1 - From dewatered sludge to biochar via drying and pyrolysis	Incineration with landfilling of ash	-2,539 (-3,529)	-2,064	-1,017	1,000	457.5
MCS - From activated wastewater sludge to struvite fertiliser via chemical processing	Incineration with ash to landfill	-2,658 (-3,710)	-2,565	-537	1,052	609.0
IMP - From meat and bone meal to fertiliser pellets via mixing and pelletising	Incineration with ash to landfill	-1,122 (-1,122)	-2,734	2,187	0	575.0
MCL - From wastewater sludge reject water to ammonia sulphate solution via chemical fixation	Conventional wastewater treatment	-509 (-3,717)	-2,792	-362	3,208	564.0
MTS2 - From dewatered sewage sludge to calcium phosphate via drying, mono-incineration and chemical extraction	Incineration with landfilling of ash	23 (-977)	-717	30	1,000	289.0
FCL - From liquid manure to acidified slurry via in-field acidification	No further processing	489 (-186)	-211	58	675	33.9

Case	Baseline	GSC in total (excl. value chain costs)	Social costs of nutrient losses	Social costs of GHG emissions	Estimated value chain costs	Social value of BBF production
		€ per functional unit				
MML - From municipal and industry-based digestate to liquids and solids via separation	No further processing	1,002 (2)	0	2	1,000	0.0
FMS - From manure digestate to liquids and solids via settling and separation	No further processing	1,400 (178)	0	178	1,222	0.0
FMP1 - From digestate to manure granules via drying and granulation	No further processing	1,398 (156)	22	130	1,242	-3.5
FMP2 - From plant based digestate to organic fertiliser pellets via separation, drying and pelletising	No further processing	1,487 (461)	280	136	1,027	-45.0
Average		**-416 (-1,489)**	**-1,257**	**39.74**	**1,073**	**272**

Table 4 shows that the social costs of nutrient losses are negative on average, indicating a societal benefit from improved nutrient retention. In contrast, social costs related to GHG emissions are slightly positive on average. Estimated value chain costs are positive for all cases, reflecting investments and operational costs associated with BBF production. The social value of BBF production varies across cases and is zero or negative in cases where nutrient recycling does not differ from the baseline.

4.2. BBF market competitiveness

From the perspective of value chain owners, market competitiveness depends on the actual production cost per unit of recycled nutrients. Table 5 presents the estimated BBF production costs per kilogram of N and P, independent of baseline comparisons.

Table 5. BBF production prices for the considered value chains (ranked similar to Table 3 and 4).

Case	Baseline	Estimated value chain costs	Amount of N and P in produced BBF	Business costs per recycled mass of nutrients
		€ per functional unit		€ per kg N and P
MCG - From human urine to fertiliser granules via source separation, chemical fixation and drying	Conventional wastewater treatment	1,134	818	1.39
MTS1 - From dewatered sludge to biochar via drying and pyrolysis	Incineration with landfilling of ash	3,000	799	3.75
MCS - From activated wastewater sludge to struvite fertiliser via chemical processing	Incineration with ash to landfill	3,157	639	4.94
IMP - From meat and bone meal to fertiliser pellets via mixing and pelletising	Incineration with ash to landfill	2,792	1,000	2.79
MCL - From wastewater sludge reject water to ammonia sulphate solution via chemical fixation	Conventional wastewater treatment	3,208	810	3.96
MTS2 - From dewatered sewage sludge to calcium phosphate via drying, mono-incineration and chemical extraction	Incineration with landfilling of ash	1,000	360	2.78
FCL - From liquid manure to acidified slurry via in-field acidification	No further processing	675	1,000	0.68

Case	Baseline	Estimated value chain costs	Amount of N and P in produced BBF	Business costs per recycled mass of nutrients
		€ per functional unit		€ per kg N and P
MML - From municipal and industry-based digestate to liquids and solids via separation	No further processing	1,000	722	1.39
FMS - From manure digestate to liquids and solids via settling and separation	No further processing	1,222	1,102	1.11
FMP1 - From digestate to manure granules via drying and granulation	No further processing	1,242	951	1.31
FMP2 - From plant based digestate to organic fertiliser pellets via separation, drying and pelletising	No further processing	1,027	216	4.75
Average		**1,769**	**765**	**2.62**

Using an estimated long-term average market price of € 1.08 per kg N and P in mineral fertilisers, only one of the assessed value chains achieved production costs below this threshold.

5. Discussion

The results demonstrate that the environmental, climate and socio-economic performance of BBF value chains is highly context-dependent and strongly influenced by baseline conditions, waste type, and processing choices. Across the assessed cases, the highest nutrient recycling impacts were observed in value chains replacing incineration or landfilling, particularly those based on municipal waste streams such as wastewater sludge, urine and meat and bone meal. In these cases, baseline scenarios involve substantial nutrient losses, meaning that BBF production enables the recovery of nutrients that would otherwise be permanently removed from the agricultural system. This explains why these value chains consistently achieved high NRI values, often reaching 100%.

In contrast, value chains based on farming wastes, especially digestate and manure, generally showed limited improvements in nutrient recycling relative to their baselines. This outcome reflects the fact that agricultural systems in the Baltic Sea Region already exhibit high levels of nutrient recycling through direct field application of manure and digestate, which is well established in both practice and policy. As a result, additional processing steps aimed at producing BBFs from farming wastes often do not increase nutrient recycling and may even lead to marginal nutrient losses during processing. In such contexts, BBF production provides limited additional value from a nutrient recycling perspective, unless it enables other benefits such as nutrient concentration for long-distance transport or regulatory compliance.

Climate performance further highlights the trade-offs inherent in BBF production. While several value chains achieved substantial emission reductions through avoided mineral fertiliser production and reduced organic waste disposal, others exhibited increased GHG emissions. These increases were primarily associated with higher energy consumption, additional transport requirements, and losses of carbon-rich organic matter, particularly in thermally intensive processes such as drying, pyrolysis, and mono-incineration. This confirms that BBF production cannot be assumed to be climate beneficial by default and that technology selection plays a decisive role in determining net climate outcomes.

From a socio-economic perspective, the GSC indicator reveals that BBF production delivers societal benefits on average, but only in a subset of cases. Five of the eleven value chains exhibited negative GSC values, indicating that the societal value of reduced nutrient losses, avoided emissions, and domestic fertiliser production outweighs the associated societal costs, including the processing costs. Notably, four of these five cases are based on municipal waste streams, reinforcing the conclusion that BBF production is most justified where baseline waste management practices involve high environmental and economic burdens. Conversely, farming-based value chains dominate among those with positive GSC values, reflecting limited additional societal gains compared to already efficient baseline practices.

When value chain costs are excluded from the socio-economic assessment, seven value chains demonstrate a net societal benefit. This distinction is important, as value chain costs represent business economics rather than societal costs, yet they remain decisive for investment decisions. The results therefore highlight a structural misalignment between societal benefits and private incentives: several BBF value chains are beneficial for society but remain unattractive from a business perspective due to high processing costs and low market prices for recycled nutrients.

This misalignment becomes particularly evident in the analysis of market competitiveness. When assessed solely on production costs per kilogram of N and P, only one value chain achieves competitiveness with mineral fertilisers at current market prices, even before accounting for profit margins. This finding underscores that BBF production is presently viable only in niche situations, typically where alternative waste management options are costly or restricted by regulation. The low willingness of farmers to pay for BBFs, often at levels significantly below mineral fertiliser prices, further constrains market uptake and reinforces the dependence on policy support mechanisms.

Taken together, the discussion indicates that BBF production is not a universally efficient solution but a targeted strategy whose relevance depends on baseline waste management, regulatory context, and processing efficiency. Municipal waste-based BBFs show higher socio-economic potential because they address systemic nutrient losses that cannot be resolved through existing agricultural practices. In contrast, farming-based BBF production often struggles to justify additional processing unless driven by specific policy objectives, such as nutrient redistribution or pollution control.

6. Conclusions

This study assessed eleven value chains for the production of BBFs from organic wastes in the Baltic Sea Region using a custom evaluation method integrating nutrient recycling, climate impact, and socio-economic performance. The results show that BBF production delivers moderate but highly variable benefits, strongly shaped by baseline conditions, waste type, and processing technology. Value chains replacing incineration or landfilling, particularly those based on municipal waste streams, demonstrate the highest nutrient recycling impacts and the greatest socio-economic value, whereas farming-based value chains generally provide limited additional benefits relative to existing practices.

Climate impacts vary widely, reflecting trade-offs between avoided emissions from mineral fertiliser substitution and increased emissions associated with energy use, transport, and organic matter losses. Socio-economically, fewer than half of the assessed value chains are justified when accounting for full value chain costs, although a larger share becomes justified when considering societal benefits alone. From a market perspective, BBF production remains largely uncompetitive with mineral fertilisers, with only one value chain achieving cost parity under current conditions.

Overall, the findings reveal a clear gap between policy ambitions for nutrient recycling and the economic realities of BBF production. Closing this gap will require targeted policy instruments that internalise environmental benefits and redirect societal value to value chain operators, alongside continued technological optimisation and improved product quality. Without such measures, BBF deployment is likely to remain limited to specific contexts where baseline waste management options are costly or restricted. A more comprehensive assessment of end-user perceptions, market development pathways, and policy frameworks is therefore essential to identify which BBF value chains can realistically be scaled and which should remain niche solutions, as further explored in complementary work (Foged et al., 2025).

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Annex 1: Not longlisted solutions

The following table lists the solutions that were not longlisted, in an random order.

Sector *	TRL	Case	Main solution provider
M	8	From municipal biowastes to digestate and compost via dry digestion and composting	HSY
F	9	From digestate to liquid and solid fertiliser via separation	Jeppo Biogas
M	9	Local solution for handling biowastes	Stormossen
F	9	Digestate from livestock manures and other wastes via anaerobic digestion	Viskaalin
F/I/M	6	Developing a system for producing concentrated ammonium compounds and phosphorus rich soil improvers with chemical precipitation and membrane technology	NPharvest
-	9	From raking and pruning wastes to growing media via chopping	Kekkilä
I	9	Organic fertiliser pellets from meat and bone meal via mixing and pelletising	DAKA
-	9	Captured ammonia nitrification system	Green Circle
F/I/M	8	Piloting growing media production based on any kind of organic wastes that is composted and inoculated with bacteria	Biopallo
F/I	9	Digestate and biomethane from a variety of food industry wastes and manure via anaerobic digestion	Demeca-WeKas
F	9	Piloting production of separation liquids and compost from food wastes and other organic wastes via anaerobic digestion	Gasum
-	5	Sludge transfer service	Lietteensiirto
F	7	From digestate to solid and liquid biofertiliser through phase separation	More Biogas

** M = Municipal wastes, F = Farming wastes, I = industry wastes*

The solutions are displayed in poster-form below, presenting the cases in a structured way and explaining under “Overall assessment” the various reasons for not proceeding with these cases.

One exception is the Gasum case, since they did not allow the presentation of the value chain in this report. Interested can find information about the Kuopio biogas plant here - https://www.gasum.com/en/gasum/supply-chain/biogas-plants/kuopio-biogas-plant/. The case was not longlisted since the data and information provided were not giving possibility for understanding the involved processes and material and nutrient flows.

TRL 8

From municipal biowastes to digestate and compost via dry digestion and composting

Solution / importance

HSY, Helsinki Region Environmental Services Authority, is in 2025 establishing facilities for intensifying the processing of biowaste for agricultural uses. The facilities increases the renewable energy production with 65-70% compared to earlier processing, while generating both renewable electricity and heat. 80 % of the biowaste will be digested, which decreases earlier composting profoundly.

THE VALUE CHAIN

WASTE COLLECTION

Location: HSY, Ämmässuontie 8, Espoo, FINLAND

Type: Separated, organic wastes from households (whereof 46% food wastes). Annually 540,000 ton is collected, containing 65 t P and 440 t N.

Average transport: App. 30 km.

Other consumables: Bulking agent.

Way of storing: Immediate transport to treatment site.

Alternative waste disposal / baseline: Replaces a system, where earlier alone 45% was dry digested.

PROCESSING

Location: As for waste collection.

Processing technology: Dry, anaerobic digestions of the finest part of the biowastes. Windrow composting of the rough part of the biowaste and the digestate separation solids.

Average transport: None.

Other consumables: No chemicals used.

End and by-products: 28,000 t digestate, containing 2.8 kg N and 5.6 kg P per ton. 6,000 t compost, containing 15 kg N and 6.7 kg P per t. Biogas production 10,000 MWh/a (current production)

BIO-BASED FERTILISER

Location: Not known

Further processing: No further processing

Storage: Storage basins for digestate.

Market: Utilization of the digestate is arranged through a contractor.

Specific labelling: suitable for organic farming.

Average transport: -

OVERALL EVALUATION

Undoubtedly, HSY is with the described value chain improving the processing seen from environmental and climate perspectives.

However, the abovementioned information makes it clear that the nutrient recycling impact is low and greenhouse gas emissions high due to the continued use of composting.

TRL 7

From digestate to liquid and solid fertiliser via separation

Solution / importance

The regional biogas plant, producing the digestate, is one of the largest in Finland. The largest share of the influent is livestock and chicken manure types, arriving there via a pipeline, co-digested with various wastes from industries in the agri-food sector, among other slaughterhouse wastes, vegetable wastes and fish wastes. Separating the digestate allow especially the phosphorus to be transported to areas in deficit.

THE VALUE CHAIN

WASTE COLLECTION

Location: Läntinen Jepuantie 288, 66850 Jepua, Ostrobothnia

Type: 142,000 t digestate from dry and wet digestion, containing 639 t N and 142 t P per year.

Average transport: None.

Other consumables: -

Way of storing: None.

Alternative waste disposal / baseline: Local use of un-separated digestate as fertiliser, causing an oversupply of phosphorus.

PROCESSING

Location: As waste collection.

Processing technology: Mechanical separation.

Average transport: None.

Other consumables: None

End and by-products: At the moment digestate from dry process is separated, amount 6,000-8,000 t/a: Liquid fraction: 9.6% DM, 8.1 kg N, 4.3 kg NH_4-N/t, 1.5 kg P/t. Solid fraction: 31.7% DM, 3.0 kg N, 2.2 kg NH_4-N and 2.8 kg P/t. Digestate from wet process is used as such in agriculture. They will start to separate 2/3 of the wet digestate soon. Without separation: 3.6% DM, 3.8 kg N, 2.8 kg NH4-N and 0.9 kg P/t

BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: None.

Storage: Liquids are stored in tanks or directly delivered to in farmer customers' tanks. Separation solids are stored in a covered area for some weeks.

Market: Field farming in Uuskaarlepyy municipality.

Specific labelling: The fertilizer is approved for use in certified organic farming.

Average transport: 35 km

OVERALL EVALUATION

More advantageous nutrient recycling processing at Jeppo Biogas is only at the planning stage. The separation of digestate from the wet digestion process is not yet operational, which does not support the separation of N and P. Therefore, there is no clear and concrete value chain for which data and information are available and which would allow an assessment of the impact of nutrient recycling and emission reduction.

Stormossen – local solution for handling biowastes

Solution/ importance: The solution enables local nutrients to circulate. Transportation is minimized and only local. When local inhabitants see how the end-products can be used, they become more interested in sorting and managing their waste. Vehicle biogas is sold in company's two filling stations by the highway. Secondly electricity is produced from the biogas, and it's used in the own plant or sold to the grid. Process has been streamlined by outsourcing the mixing and sales to an external business partner.

THE VALUE CHAIN

WASTE COLLECTION

Location: Biowaste comes from South-Ostrobothnia, Ostrobothnia (Pohjanmaa, Central Ostrobothnia and Northern Ostrobothnia. Sewage sludge comes from Vaasa region.

Type: Sewage sludge, biowaste

Average transport: Sludge: 10 km

Other consumables: -

Way of storing: Biowaste goes directly to the treatment. There is a storage building for biowaste as a backup for couple of days storage.

Alternative waste disposal / baseline: Incineration.

PROCESSING

Location: Ostrobothnia (Pohjanmaa, Koivulahti), FINLAND

Processing technology: Biowaste: Mechanical pre-treatment then an anaerobic mesophilic digestion and then digestate is dewatered and then composted.

Average transport: -

Other consumables: -

End and by-products: Digestate (composted to reach requirements), biogas, process water, some plastics and metal

BIO-BASED FERTILISER

Location: Ostrobothnia (Pohjanmaa, Koivulahti)

Further processing: None.

Storage: Sludge digestate and biowaste compost are stored outside in different areas on asphalt area as piles.

Market: Mentioned under location.

Specific labelling: In process of getting Laatulannoite-certificate (Quality fertilizer). ISO14001 (Environment), ISO9001 (Quality), ISO45001 (Health and safety)

Average transport: -

OVERALL EVALUATION

An assessment of the value chain with respect to environmental and climate impact was not possible since no concrete and quantified data and information was provided on material flow and nutrient NP turnover.

TRL 9

Digestate from livestock manures and other wastes via anaerobic digestion

Solution / importance

This Viskaalin biogas plant, commissioned in 2024, combines the production of renewable energy with improved recycling of nutrients from organic wastes, including livestock manures, feed wastes and wastes from the food processing industry.

THE VALUE CHAIN

WASTE COLLECTION

Location: Oulu region, Muhos

Type: Organic wastes, including livestock manures, feed wastes and wastes from the food processing industry.

Average transport: Transport of all masses on average 10-15 km.

Other consumables: None.

Way of storing: Directly fed into the digester, some kept in an immediate storage.

Alternative waste disposal / baseline: The baseline is to use the livestock manures as fertiliser in raw form, and delivery of other organic wastes to municipal waste collection.

PROCESSING

Location: Viskaalin eovillage Ltd., 91500 Muhos

Processing technology: Anaerobic digestion.

Average transport: None.

Other consumables: None

End and by-products: Digestate about 260,000 t/a.

About: A digital planning platform for farming plans optimizes the use of the fertilizer with the need of each field block.

BIO-BASED FERTILISER

Location: Viskaalin ecovillage Ltd.

Further processing: None.

Storage: Slurry tanks.

Market: All is used by the company itself.

Specific labelling: None.

Average transport: 20 km.

OVERALL EVALUATION

This value chain is undoubtedly beneficial for production of biogas and the value of that.

However, the value chain was not established for a main purpose of nutrient recycling, hindering an assessment of this aspect. In addition, assessment of environmental and climate impacts are not possible since the provided information does not quantify nutrient turnover or details about the biogas production.

TRL 6

Developing a system for producing concentrated ammonium compounds with chemical precipitation and membrane technology

Solution / importance

NPHarvest's Nutrient Catcher is a nutrient recovery process for wastewaters or other liquid waste streams with a high nutrient content. Phosphorus is precipitated with lime and nitrogen with ammonium in the form of stripping with hydrophobic membranes. The final product is pure ammonium salt that has wide range of applications. In addition, the process generates phosphorus-rich soil improver, but it is not considered in this value chain.

THE VALUE CHAIN

WASTE COLLECTION

Location: Client specific

Type: Liquid and high nutrient content (500+ mg/l NH_4^+-N) (Ammonia-nitrogen).

Average transport: Existing wastewater collection structures. NPHarvest processes it where it is already collected.

Other consumables: Client specific

Way of storing: -

Alternative waste disposal / baseline: Wastewater is always collected and treated.

PROCESSING

Location: Client specific

Processing technology: NPHarvest technology

Average transport: Client specific

Other consumables: Chemicals, clients specific, examples: Calcium hydroxide, sulfuric acid, nitric acid.

End and by-products: Ammonium sulfate or ammonium nitrate: 10 % N in liquid fraction and 20 % N in solid crystal. No phosphorus. Density: For liquids: about 1.35 kg/l (10 % N-solution incl. 350 g salt). Waste products: Treated wastewater with a high pH.

BIO-BASED FERTILISER

Location: -

Further processing: Liquid needs to be crystallized. To be useful for the end user (farmer), the product needs to have a balanced amount of different micro and macronutrients and be pelletized.

Storage: -

Market: -

Specific labelling: CE marking. (Debate ongoing whether organic is applicable for NPHarvest products).

Average transport: Client specific

OVERALL EVALUATION

This value chain has not yet reached market maturity, and no test, demo, reference or pilot plant exists at this stage. It is thus not possible to evaluate concrete value chains.

However, the value chain has potential to replace and improve current widespread practices of wastewater processing, which from several perspectives is problematic since they mean a very low recycling of nutrients.

TRL 9

From raking and pruning wastes to growing media via chopping

Solution / importance

Kekkilä offers concrete solutions for the circular economy and green construction. The concept recycles materials produced in the city, and Kekkilä is able to offer a solution for implementing a closed cycle. City residents would typically deliver the material to the collection points themselves. As a general rule, municipal waste management companies take the material for free of charge from city residents.

THE VALUE CHAIN

WASTE COLLECTION

Location: Location is specific to locality.

Type: Mainly garden and raking waste. Ability to process different types of materials.

Average transport: Usually less than 15 km

Other consumables: Way of storing: In the storage area in the open field

Alternative waste disposal / baseline: primarily landfilling, while another option is to use the branches and alike as structure material in windrow composting.

PROCESSING

Location: Any municipality

Processing technology: -

Average transport: -

Other consumables: -

End and by-products: -

BIO-BASED FERTILISER

Location: Any municipality

Further processing: -

Storage: -

Market: Kekkilä is Finland's leading manufacturer of growing mediums for landscaping industry.

Specific labelling: -

Average transport: -

OVERALL EVALUATION

Kekkilä operates in a circular economy with organic and mineral materials.

However, the main objectives of this value chain is not to recycle nutrients, and there is no information available about the turnover of N and P. Thus, there is no clear and concrete data and information available that would allow an assessment of nutrient recycling and emission reduction potentials.

TRL level: 9

Organic fertiliser pellets from meat and bone meal via mixing and pelletizing

Solution / importance: Øgro is in the main produced on meat and bone meal from dead animals. Other materials are added to match the nutrient content to the demand for specific crops. Øgro can be used as fertiliser at organic certified farms, in Denmark up to a regulated level of 107 kg N per ha.

THE VALUE CHAIN

WASTE COLLECTION

Location: Hedensted (?) in Central Denmark Region.

Type: The main organic waste, mainly meat and bone meal, is a by-product from the processing of dead animals and slaughterhouse wastes into bio-diesel.

Average transport: None.

Other consumables: None.

Way of storing: None - is delivered directly to the processing.

Alternative waste disposal / baseline: Petfood ingredient, incineration.

PROCESSING

Location: Hedensted.

Processing technology: Includes drying, balancing nutrients (see below) and pelletizing.

Average transport: None.

Other consumables: The processing is energy demanding. Other materials added includes calcium, potassium, vinasse, and potassium sulphate.

End and by-products: The products are a series of bio-based fertilisers with nutrient contents aiming to match various crops.

BIO-BASED FERTILISER

Location: Hedensted.

Further processing: Bagged in big bags with 750 kg.

Storage: Conventional warehouse.

Market: Mainly organic farms in Denmark.

Specific labelling: As organic fertiliser that can be used for organic farming.

Average transport: 150 km (estimated)

OVERALL EVALUATION

This value chain is a very good example of nutrient recycling, assuming it brings benefit for environment and climate.

However, we do not have access to data and information for performing more concrete assessments of the impacts on environment and climate.

TRL 9

Captured Ammonia Nitrification System

Solution / importance

The patented and commercially ready CANS system enables to convert conventionally obtained ammonium sulphate solution from farms / biogas facilities into high-end nitrate fertilizer to be used as primary nutrition in green houses

THE VALUE CHAIN

WASTE COLLECTION

Location: Lithuania to Netherlands

Type: Captured ammonia from farms, biogas facilities, WWTP, slaughterhouses and CO2

Average transport: Raw materials can be transported up to 1,000 km. Currently transported from NL and FR to Lithuania.

Other consumables: CO2, Water

Alternative waste disposal / baseline: Spreading the ASL locally, which troublesome in west specific regions where raw materials exceed limits

PROCESSING

Location: Pakuonis village, Prienai region, Kaunas district, Lithuania

Processing technology: nitrification bacteria powered bio-reactor

Average transport: None

Other consumables: low energy demand and human resources

End and by-products: [3.5]

Product: Equal alternative to conventional mineral nitrate fertilizers. Organically certified in USA. By-product: discharge process water with sulfur and soluble microbial carbon

BIO-BASED FERTILISER

Location: Kaunas, Lithuania

Further processing: None

Storage: As conventional fertilizer alternatives

Market: USA, Europe

Specific labelling: None (As mineral alternative products are ADR).

Average transport: None

OVERALL EVALUATION

Green Circle's CANS system is according to the description for application of bio-based fertilisers, in specific ammonia sulphate solution to greenhouse crops, which is outside the scope for value chains to produce bio-based fertilisers from nutrient containing organic wastes.

TRL 8

Piloting growing media production based on any kind of organic wastes that is composted and inoculated with bacteria

Solution / importance
Practically any type of organic waste is used for the production of bacteria inoculated compost that is pelletized. The product is sold as a growing media, organic fertiliser and soil improver.

THE VALUE CHAIN

WASTE COLLECTION

Location: Collection area: any

Type: Practically any biomass source, for example animal-derived, vegetable-derived pulps, digested or non-digested: biowaste, sewage sludge, manure; waste from the food industry (e.g. bone pulp), side streams from the forest industry, field biomass, etc.

Average transport: -

Other consumables: Customer specific

Way of storing: -

Alternative waste disposal / baseline: Composting or anaerobic digestion.

PROCESSING

Location: Biopallo Systems Oy, Telkkistentie 2, Kuopio North Savo, Finland

Processing technology: Enhanced composting. Bioreactor and microbial (tailored) inoculation. Sanitation for animal side products, f.e. slaughter waste: in 70 °C, at least for 1 h. (Post-composting)

Average transport: Customer specific

Other consumables: Customer specific.

End and by-products: Final products: Soil improver / Growing media / Organic fertilizer

BIO-BASED FERTILISER

Location: -

Further processing: Customer specific.

Storage: Customer specific

Market: (*Marketing the equipment:* Primarily in Finland, potential customers are surveyed.

Specific labelling: Environmental permit and facility approval from the Finnish Food Agency.

Average transport: Customer specific

OVERALL EVALUATION

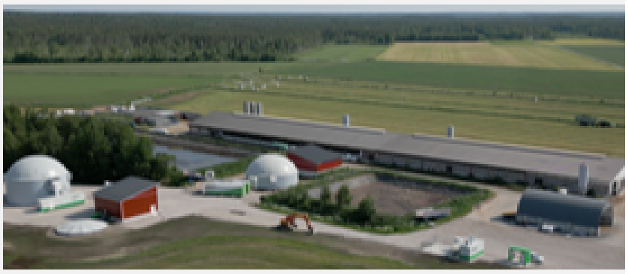
This value chain has not yet reached market maturity but is technologically situated in the later development stages. Considering the available information, it was not possible to assess possible nutrient recycling and emission reduction impacts.

TRL 9

Digestate and biomethane from a variety of food industry wastes and manure via anaerobic digestion

Solution / importance

The biogas plant is digesting a variety of wastes, including wastes from the food industry, which earlier were handled as municipal wastewaters. The anaerobic digestion process reduces odour emissions from manure spreading at farms, which increases local acceptability. The biogas is processed into biomethane, sold to local from a filling station near the plant.



THE VALUE CHAIN

WASTE COLLECTION

Location: Central Ostrobothnia, Finland

Type: Food and feed industry sludge and liquids, livestock manures and other.

Average transport: None

Other consumables: Labour costs are low, because it's done as a farm worker's side job.

Way of storing: Some in tight and covered containers, other inputs are fed directly.

Alternative waste disposal / baseline: Industry wastes would go to the wastewater treatment plant. Livestock manure would be spread on the fields as raw manure.

PROCESSING

Location: WeKas Oy, Härkänevantie 465, 69300 Toholampi, Central Ostrobothnia, Finland

Processing technology: Crushing. Heat treatment for sanitization of industry wastes. Anaerobic digestion in reactor for about 40 days. The biogas is converted to biomethane.

Average transport: None

Other consumables: None

End and by-products: End-products: Digestion residue: 9,300 t/y with 0.3% N and 0.08 % P

BIO-BASED FERTILISER

Location: As for waste processing

Further processing: None

Storage: No pre-stocking (only a few external inputs). After processing, slurry ponds.

Market: No separate marketing. Communication through networks works. There would be more input material than what can be produced into fertilizers.

Specific labelling: No

Average transport: The facility is in the middle of the fields, so no separate transport.

OVERALL EVALUATION

This value chain is undoubtedly beneficial for production of biogas and the value of that.

However, the value chain was not established for a main purpose of nutrient recycling, hindering an assessment of this aspect.

Also, it is considered that an overall environmental and climate impact of the value chain could be severely hampered by the way the digestate is stored in open ponds.

TRL 5

Sludge transfer service

Solution / importance

Kuljetus Tero Liukas Ltd. provides precise nutrient analysis during sludge transfer and on site. The analysis is taken from factually mixed sludge showing the nutrient balance of the sludge pool. There is no over- or under-fertilization, with this solution, it is possible to define precise nutrient application amounts for fields. The most optimal prescription application possible for manure-based digestates.

THE VALUE CHAIN

WASTE COLLECTION

Location: Varsinais-Suomi, Western Finland

Type: Livestock manure and sludge, mainly pig manure

Average transport: 20 km

Other consumables: -

Way of storing: Directly in the facility.

Alternative waste disposal / baseline: manure or degistate would be used as fertilizer without up-to-date information on nutrient concentrations

PROCESSING

Location: Used currently at Gasum's Vehmaa facility. Tero Liukas' company and Gasum's cases support each other. Address: Kalannintie 191, 23200 Vinkkilä, FINLAND

Processing technology: The technology is NIR-analysis of the sludge

Average transport: NA

Other consumables: NA

End and by-products: NA

BIO-BASED FERTILISER

Location: Loimaa, Vännilläntie 139, 32440 Alastaro Southern Finland

Further processing: -

Storage: -

Market: Farmers as customers. The customer base is old. Telemarketing. For 110,000-120,000 tonnes.

Specific labelling: No

Average transport: The transport company itself always delivers. If the farmers themselves want to pick up, then less than 5 km.

OVERALL EVALUATION

Kuljetus Tero Liukas Ltd. transports sludge, which is analysed by use of NIRS technology. These activities are outside the scope of producing bio-based fertiliser from organic wastes.

TRL 9

From digestate to solid and liquid biofertilizer through phase separation

Solution/ importance

More Biogas in Kalmar, Sweden, is a biogas production facility that converts organic waste, such as agricultural residues and manure, into renewable energy in the form of biogas. The facility has started performing phase separation of the digestate, producing nutrient-rich liquid and solid bio-fertilizers, which are returned to farmland, supporting a circular economy approach.

THE VALUE CHAIN

WASTE COLLECTION

Location: Kalmar region, Sweden

Type: Digestate based on manure (52%), food industry wastes (28%), and household food waste (20%).

Average transport: 15.9 km

Other consumables: None.

Way of storing: Sealed tanks or covered containers.

Alternative waste disposal / baseline: Direct land application as fertilizer for the manure, waste would otherwise follow the municipality's handling.

PROCESSING

Location: Lackeby, Sweden

Processing technology: Phase separation using centrifugation and screw pressing, to produce solid and liquid bio-fertilizers for agricultural use.

Average transport: Same as collection.

Other consumables:

Energy: 11.6 kWh/t and 90 MJ/t for centrifugation and screw pressing.

End and by-products: Biogas and biofertilizer (liquid – NPK 9.7:1:41, DM 4.5%; solid – NPK 28:14:1, DM 40%).

BIO-BASED FERTILISER

Location: Kalmar region, Sweden

Further processing: None

Storage: Sealed tanks or covered containers.

Market: Nearby farms.

Specific labelling: None.

Average transport: Same as collection.

OVERALL EVALUATION

The assessment of the case was discontinued since it was clarified that the value chain in question is not anymore in operation but given up.

Annex 2: Longlisted solutions

The following table lists the solutions that were longlisted, in an random 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

** H = Municipal wastes, F = Farming wastes, I = industry wastes*

The solutions are displayed in poster-form below – except the not specified solution, presenting the cases as well as the assessments of them in a uniform and structured way.

TRL 8

Piloting dewatered sewage sludge to biochar through drying and pyrolysis

Solution/ importance
Dried and pyrolyzed biosolids from wastewater treatment, producing low-PAH biochar that meets Danish standards for farmland application. The process strongly reduces or eliminates organic pollutants, pathogens, and microplastics, resulting in biochar.

THE VALUE CHAIN

WASTE COLLECTION

Location: Adelers Alle 198 B 4540 Fårevejle Denmark.

Type: Sewage sludge, 1,000 tonnes per year, 3% P, 4% N of DM.

Average transport: None.

Other consumables: -

Way of storing: Containers.

Alternative waste disposal / baseline: Incineration with landfilling of ash.

PROCESSING

Location: As for waste collection.

Processing technology: HECLA Setores 1.000 by AquaGreen, integrated steam drying and pyrolysis.

Average transport: None.

Other consumables: Electricity.

End and by-products: The end-product is 350 tonnes biochar per year with 5-6% P and 2-3% N.

Syngas and bio-oil are generated but combusted immediately at site. Condensed vapour from sludge drying is returned to wastewater treatment plant.

BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: Biochar is handled in big bags.

Storage: Big bags.

Market: Agriculture and urban landscaping (parks etc.) in Denmark and Sweden.

Specific labelling: None.

Average transport: None.

Environmental impact: The Nutrient Recycling Impact* is 78%.
Climate impact: The Direct Emission Impact* is –13.2 tonnes of CO_2-eq for every 1,000 kg N and P in the processed sewage sludge.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product contains P but also carbon and micronutrients. Potential for carbon credits and reduced transport.

End user acceptance: Easy to store. The carbon and P content is high, but the plant availability of P is low and zero for the N content. Scepticism due to sewage sludge origin.

Policy implications: Matches EU goals and the critical phosphorus focus. Faces hurdles with EU FPR and scattered policy updates. Lacks incentives, but carbon market may help.

TRL 9

From digestate to separation liquids and solids via separation

Solution / importance

Bio10 is a biogas plant that separate the digestate for having separation liquids as a valuable fertiliser. The digestion in mainly based on organic household wastes, including food wastes and some food industrial wastes, all collected in the central and eastern part of Finland.

THE VALUE CHAIN

WASTE COLLECTION

Location: Puhoksentie 15, 82500 Kitee, Finland.

Type: Digestate.

Average transport: None

Other consumables: -

Way of storing: None.

Alternative waste disposal / baseline: Use of digestate as fertiliser without further treatment.

PROCESSING

Location: As for waste collection.

Processing technology: Separation.

Average transport: None

Other consumables: None.

End and by-products: The end-product is separation liquids: 7,400 t per year, containing 4% DM, 5.3 kg N, 3.5 kg NH_4-N and 0.6 kg P per ton. A by-product is 1,100 t separation solids, containing 22% DM 22%, 6 kg N, 0.6 kg NH_4-N and 1.7 kg P per t.

BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: No packaging. In bulk, solid or liquid.

Storage: Covered containers for liquids. Compact, drained asphalt field with solids.

Market: Eastern and central part of Finland.

Specific labelling: suitable for organic farming.

Average transport: 100 km.

Environmental impact: The Nutrient Recycling Impact* is 0%.
Climate impact: The Direct Emission Impact* is 0 tonnes of CO_2-eq for every 1,000 kg N and P in the processed digestate.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product is allowed in organic farming. The processing is simple and flexible in scale. Large N and P flows (raw material) are available.

End user acceptance: Bulk products difficult to store and apply at crop farms. The origin on household wastes (ex. sewage) and food industry by-products is well accepted.

Policy implications: Low-refinement solution aligned with EU goals. EU FPR-compatible and organic-accepted. Strong policy support is still lacking.

TRL 9

From raw to acidified slurry via in-field acidification

BioCover's SyreN system adjust the pH of slurry during field spreading to a level that moves the ammonia-ammonium equilibrium to ammonium, around pH 6.4 by use of sulfuric acid. This reduces the emission of ammonia with typically 50% and saves the loss of typically 15 kg N per ha. Also, the plant availability of phosphorus is typically doubled, so all-in-all, NP recycling is increased and pollution reduced. The sulfur in the acid reduces the need for sulfur fertilising.

THE VALUE CHAIN

WASTE COLLECTION

Location: An example of a real case is Rostgård Maskinstation (contractor - https://www.rostgaardmaskinstation.dk/) who has 3 SyreN systems and services farmers in the region with slurry spreading.

Type: Slurry / liquid livestock manures.

Average transport: None.

Other consumables: NA

Way of storing: NA

Alternative waste disposal / baseline: The alternative would be field spreading of the slurry in raw form, without in-field acidification.

PROCESSING

Location: As for waste collection.

Processing technology: In-field slurry acidification. 1 SyreN system has a max capcity of 120.000 tonnes slurry per season.

Average transport: None.

Other consumables: Averagely 1.5 litre 96% sulfuric acid per ton slurry, with variation depending on slurry type, its buffer capacity and its starting pH level.

End and by-products: Acidified slurry with pH <= 6.4.

BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: None.

Storage: None.

Market: EU, mainly DK and DE.

Specific labelling: None.

Average transport: None.

Characteristics of the fertiliser: It is a liquid with a density of 1. The chemical content depend on the slurry type that is acidified. An example of the chemical content is: 5.5% dry matter, 4.5 kg N, 3.0 kg NH_4-N, 1.2 kg P and 2.5 kg K per tonnes.

Environmental impact: The Nutrient Recycling Impact is 7%, since it means that more N is available to the crop.

Climate impact: The Direct Emission Impact* is 0.8 tonnes of CO_2-eq for every 1,000 kg N and P in the processed slurry.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The losses of N are reduced. The scale is flexible. No large investments or operation costs.

End user acceptance: Product reduces N losses from raw slurry and contain additional sulphur. Heavy and specific machinery required for application. Risk of soil compaction.

Policy implications: Aligned with EU nutrient use efficiency goals. Not directly linked to recycling. Incentives for nitrogen losses reduction are limited.

TRL 9

From digestate to separation solids and liquids via settling and separation

Solution / importance

Digestate based on pig manure is separated into liquid and solid fractions via natural settling followed by separation.

T H E V A L U E C H A I N

WASTE COLLECTION

Location: Tuomarlantie 59, 23200 Vinkkilä, Vehmaa, Southwest Finland

Type: Digestate based mainly on pig slurry.

Average transport: None

Other consumables: None

Way of storing: None

Alternative waste disposal / baseline: Use of digestate as fertiliser without further treatment.

PROCESSING

Location: As for waste collection

Processing technology: 1) Settling of solids. 2) Mixing the settled solids with subsequent mechanical separation with a screw press.

Average transport: None

Other consumables: None

End and by-products: Solid fraction: 800 t/a with 30% DM and 7.6 kg N, 3 kg NH_4-N and 4.5 kg P/t. Liquid fraction (from settling): 14,000 t/a with 2.5 kg N, 1.7 kg NH_4-N and 0.01 kg P/t. Liquid fraction (from screw press): 3,200 t/a with 4 kg N and 1 kg P/t.

BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: None.

Storage: Storage tanks for the liquid fractions are covered at the plant. Additional remote storages available. Covered storage for the solid fraction at the plant.

Market: Farms nearby

Specific labelling: None

Average transport: Liquid fraction to the fields within the radius of 5.5 km pipeline + umbilical system from the storage tanks.
Solid fraction is transported with trucks to an average distance of 70 km.

Environmental impact: The Nutrient Recycling Impact* is 0%.
Climate impact: The Direct Emission Impact* is 2.3 tonnes of CO_2-eq for every 1,000 kg N and P in the processed digestate.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product is allowed in organic farming. The processing is simple and flexible in scale. Large N and P flows (raw material) are available.

End user acceptance: Solid product is high in P and organic matter. Bulk products are difficult to store and apply at crop farm. Risk of soil compaction. Manure is well accepted.

Policy implications: Low-refinement solution aligned with EU goals. EU FPR-compatible and organic-accepted. Strong policy support is still lacking.

TRL 7

Piloting sludge reject water to concentrated ammonium sulphate solution through chemical fixation

Solution/ importance

Aqua2N is a technology developed by EasyMining, whereby concentrated ammonium sulphate solution (ASS) is produced from reject water of wastewater sludge dewatering. The 40% concentrated ASS can be used directly as a fertilizer or as a component in fertilizer production.

THE VALUE CHAIN

WASTE COLLECTION

Location: Pilot plant at Lynetten WWTP, Denmark.

Type: Reject water from wastewater sludge dewatering.

Average transport: None.

Other consumables: NA

Way of storing: NA

Alternative waste disposal / baseline: Return of untreated reject water to wastewater treatment plant, which means nitrogen release both to the atmosphere and to recipients, and some fraction found in sludge, i.e. used in agriculture.

PROCESSING

Location: See waste collection.

Processing technology: Chemical treatment combined with centrifuge separation.

Average transport: None.

Other consumables: Sodium hydroxide, Sulphuric acid, Ammonia, Phosphoric acid, Magnesium sulphate, Electricity.

End and by-products: Liquid solution of ammonium sulphate $(NH_4)_2SO_4$, containing 8.4% N and 9.6% S (DM: NA, Density: 1). Byproducts: Reuse of precipitation agent. Treated reject-water.

BIO-BASED FERTILISER

Location: NA (not yet on the market)

Further processing: No.

Storage: Tank.

Market: NA

Specific labelling: None.

Average transport: NA (not yet on the market)

Environmental impact: The Nutrient Recycling Impact* is 100%.

Climate impact: The Direct Emission Impact* indicates decreased emissions of –4.7 tonnes of CO_2-eq for every 1,000 kg N and P in the processed sludge reject water.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product is competitive with mineral ammonium sulfate and can be CE-marked according to the FPR. The processing is flexible with respect to scale.

End user acceptance: Has high N content and additional sulphur. Difficult to store and apply at crop farm. Risk of soil compaction. Scepticism due to sewage sludge origin.

Policy implications: Supports EU goals and UWWTD implementation. Fits EU FPR, but misaligned policy updates and missing incentives limit uptake. No differentiated demand.

TRL 8

Piloting digestate to organic fertiliser pellets through separation, drying and pelletizing

Solution/ importance

EkoBalans separate digestate after addition of polymer. The separation solids are dried and pelletized into a fertilizer product, whereas the separation liquids are used for fertilising by local farms. The digestate is based on liquid pig manure, household food waste, slaughterhouse waste and other food industry byproducts.

THE VALUE CHAIN

WASTE COLLECTION

Location: Bjuv, Scania, Sweden

Type: Digestate of liquid pig manure, household food waste, slaughterhouse waste and other food industry byproducts.

Average transport: 0 (processing done at the site where waste is collected)

Other consumables: NA

Way of storing: Covered manure storage.

Alternative waste disposal / baseline: Use of the unprocessed digestate in agriculture.

PROCESSING

Location: As for collection.

Processing technology: Addition of polymer and ammonium sulphate, separation, drying and pelletising. Scrubber to remove ammonia in the exhaust from the dryer.

Average transport: 0 (processing done at site)

Other consumables: Polymer. Energy for pelletizing + drying.

End and by-products: Pellet contains 24% C, 8% N (partly added), 1.5% P, 0.3% K, 6% S, 3% Ca, 0.3% Mg + micronutri-ents. By-product: Liquid frac-tion, contains ~70% of N and ~10% of P (from digestate).

BIO-BASED FERTILISER

Location: Pellet marketed regionally by Ekobalans (Scania and Halland).

Further processing: Packaging.

Storage: Big bags, 750 kg.

Market: Currently mainly cities (parks etc.) and private households.

Specific labelling: "Certifierad Återvinning", which is a private Swedish label for quality and transparency when using digestate and compost on arable land. (RISE is the certification body)

Average transport: Up to ~150 km.

Environmental impact: The Nutrient Recycling Impact* is -1% due to a small loss during drying.

Climate impact: The Direct Emission Impact* is negative, the climate footprint being 1.7 tonnes of CO_2-eq for every 1,000 kg N and P in the processed digestate.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product contains both N, P, and other nutrients, in ratios attractive to the farmer. The scale is flexible. Large N and P flows (raw material) are available.

End user acceptance: Easy to store and apply. Nutrient content comparable to mineral fertilisers and high organic matter content. Polymer additive may reduce acceptability.

Policy implications: Matches EU goals and critical phosphorus focus. EU FPR-compatible but not organic-accepted. Limited demand and incentives.

TRL 9

From meat and bone meal to fertilizer pellet though mixing and pelletizing

Solution/ importance
Gyllebo Gödning offer fertilizer pellets, ”Biofer”, of various composition. The main raw material is meat and bone meal, one of the resulting products from processing of animal tissue (mainly fallen stock / self-dead animals). The nutrient content of the pellets is adjusted according to its intended use with minerals that are allowed in organic farming, and other components, such as vinasse.

T H E   V A L U E   C H A I N

WASTE COLLECTION

Location: DAKA A/S, Dronninglund, Denmark

Type: Meat and bone meal.

Average transport: 470 km (Dronninglund to Malmö)

Other consumables: None

Way of storing: Closed containers.

Alternative waste disposal / baseline: Incineration and ash to landfill (needs to fulfil animal by-product regulation)

PROCESSING

Location: Gyllebo Gödning has a processing factory in Malmö

Processing technology: Mixing of substrates, pelletizing, packaging in various size bags.

Average transport: NA

Other consumables: Minerals that are allowed in organic farming, and other components, such as vinasse. Energy required for processing (similar to a feed factory). ~0.04-0.175 kg CO2-ekv/kg (different Biofer products) (Cederberg et al., 2011).

End and by-products: Pellets, e.g. “Biofer 10-3-1”: 10% N, 2.6% P, 1% K, 0.5% S, 0.2% S.

BIO-BASED FERTILISER

Location: Distributed from Malmö, mainly via retailers, such as Granngården, all over Sweden.

Further processing: No

Storage: Bags of various size

Market: Estimated use in Sweden (2009): ~15 000 tonne Biofer (Cederberg et al., 2011).

Specific labelling: Permitted to use for certified Swedish organic farming that use the KRAV food label.

Average transport: Estimated 200 km from Malmö to end-user.

Environmental impact: The Nutrient Recycling Impact* is 100% since the baseline would mean a loss of all nutrients in the meat and bone meal.
Climate impact: The Direct Emission Impact* is 28.4 tonnes of CO_2-eqfor every 1,000 kg N and P in the processed meat and bone meal.
**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product can be CE-marked and is allowed in organic farming. It contains both N, P, and other nutrients. The scale is flexible.

End user acceptance: Easy to store and apply with existing machinery. Nutrient content comparable with mineral fertilisers. The origin on meat and bone meal is well accepted.

Policy implications: Matches EU goals and critical phosphorus focus. EU FPR-compliant and organic-accepted, offering better market entry.

TRL 9

From digestate to organic fertiliser pellets via separation, drying and pelletizing

Solution/ importance

PLANTEO organic fertilizer is made from agricultural and food waste-based digestate, 100% plant-based, that is separated, dried and pelletized. The product is versatile and can be used in both agriculture and private gardens.

THE VALUE CHAIN

WASTE COLLECTION

Location: Kożanówka 130, 21-533 Rossosz and Przypisówka 59a, 21-136 Firlej, Poland.

Type: 110,000 t digestate, based on agricultural and food wastes, 100% plant-based.

Average transport: None.

Other consumables: NA

Way of storing: NA

Alternative waste disposal / baseline: The alternative would be field spreading of the digestate without further processing.

PROCESSING

Location: As for waste collection.

Processing: The digestate is separated, whereafter it undergoes thermal drying and pelletizing.

Average transport: None.

Other consumables: Electricity.

End and by-products: The end-product is organic fertiliser pellets, produced in an amount of 400 t per year, containing 85% organic matter (OM), 1.85% N, 1.3% P_2O_5 and 1.25% K_2O.

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BIO-BASED FERTILISER

Location: As for waste collection.

Further processing: Packed in big bags or in 1 kg and 4 kg paper bags.

Storage: Dry, sun protected and ventilated rooms.

Market: Online sales, horticultural wholesalers, farmers current annual sales around 500 tons.

Specific labelling: Approved for use in certified organic farming.

Transport: Averagely 150 km.

Environmental impact: The Nutrient Recycling Impact* is -9%, since the majority of NH_4-N is lost during the drying process.

Climate impact: The Direct Emission Impact* is 1.8 tonnes of CO_2-eq for every 1,000 kg N and P in the processed digestate.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product can be CE-marked, is allowed in organic farming and contains several nutrients. Flexible in scale. Large N/P flows (raw material) are available.

End user acceptance: Easy to store and apply with existing machinery without risk of soil compaction. High in organic matter but low in nutrients. Raw materials are well accepted.

Policy implications: Aligned with EU goals. EU FPR-compatible and organic-accepted. Strong policy support is still lacking.

TRL 6

Testing urine to fertilizer granules through source separation, chemical stabilisation and drying

Solution/ importance

Urine is collected by using urine-diverting toilets or urinals, where the urine tank has been pre-dosed with a mix of food-grade chemicals that stabilises the nitrogen in the urine, avoiding N volatilisation. Depending on the type of installation, processing the urine into a fertiliser happens either on-site or at a drying facility. The drying process involves evaporating water, with mainly renewable energy, whereby the nutrient content is raised 25-fold. Lastly, granulation enabling farmers to use it in their conventional equipment.

THE VALUE CHAIN

WASTE COLLECTION

Location: Gotland, Sweden.

Type: Urine concentrate.

Average transport: 20 km

Other consumables: Special acid chemical mix to stabilise the Nitrogen (avoiding N volatilisation) and decrease odours.

Way of storing: IBC tanks

Alternative waste disposal / baseline: Collection by vacuum truck and transport to be treated at conventional WWT facilities.

PROCESSING

Location: Gotland, Sweden.

Processing technology: Sanitation360 Urine dehydration

Average transport: None

Other consumables:

Binding agent (compost)

200 Wh/L with heat recovery

End and by-products: Urine pellet (NPK: 15-2-4, DM: 95%, density: 1.5). By-products: No (no waste generated).

The plant availability of N and P is comparable to that of conventional chemical fertilizers.

BIO-BASED FERTILISER

Location: Gotland, Sweden.

Further processing: Packaging - bagging of product (in granules).

Storage: In bags.

Market: All that is produced is currently used as test by Gotlands Bryggeri.

Specific labelling: -

Average transport: 20 km

Environmental impact: The Nutrient Recycling Impact* is 100%.

Climate impact: The Direct Emission Impact* is -4.8* tonnes of CO_2-eq for every 1,000 kg N and P in the processed urine, among other due to avoidance of a conventional wastewater treatment processing.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product contains several macro and micronutrients and could be competitive with mineral fertilizer given its concentration. Nutrient load on WWTPs could be reduced.

End user acceptance: Easy to store and apply with existing machinery without risk of soil compaction. Scepticism towards products of human origin.

Policy implications: Aligned with EU goals, but not yet FPR-compliant. Not accepted for organic agriculture, limiting market entry. EU-level incentives remain weak.

TRL 8

Prototyping activated sludge to struvite fertilizer through chemical processing

Solution/ importance

Phosphorus is often removed from wastewater through iron (Fe-P) precipitation. This process dissolves Fe-P into iron and ortho-phosphate, which can then be converted into struvite, a plant-available, slow-release fertilizer containing phosphorus (P), nitrogen (N), and magnesium (Mg). The system involves a reduction tank for activated, excess sludge, a tube reactor, a flocculation unit, and a struvite precipitation tank at a wastewater treatment plant. The end users of this fertiliser are farmers.

THE VALUE CHAIN

WASTE COLLECTION

Location: Abwasser- u. Straßenreinigungsbetrieb der Stadt Gifhorn, Germany.

Type: Activated, excess sludge from wastewater treatment. sewage sludge 760 t dry mass with 3.8% P.

Average transport: It's an onsite technology.

Other consumables: None.

Way of storing: Sludge is typically stored in holding tanks or buffer tanks.

Alternative waste disposal / baseline: Incineration with ash to landfill.

PROCESSING

Location: As for collection.

Processing technology: Reductive Fe-P dissolution, slight acidification, Fe-precipitation, flocculation, P-precipitation as struvite.

Average transport: Delivery to Mieste, 54 km.

Other consumables: Sulfur based chemicals, flocculants, Magnesium. Electricity consumption is preliminarily measured to 29 kWh per ton sludge dry matter.

End and by-products: 120 tonnes of struvite, containing 5.7% N, 28% P_2O_5, 16% MgO. Sludge residuals are dewatered to sewage sludge.

BIO-BASED FERTILISER

Location: Mieste.

Further processing: Cleaning, blending, and granulation.

Storage: Handled in big-bags in a dry, cool, and contaminant-free environment.

Market: The market for struvite is crop producers, including farms and greenhouses, etc. It is a so-called slow-release fertiliser, where the nutrients are not readily available for the crop, but released over some weeks, typically.

Specific labelling: -

Average transport: 46 km.

Environmental impact: The Nutrient Recycling Impact* is 100%.
Climate impact: The Direct Emission Impact* is –7.0 tonnes of CO_2-eq for every 1,000 kg N and P in the processed activated sludge.

**These assessments are related to the conventional baseline, based on provided information combined with well documented scientific evidence, and the use of a standardised and custom-made methodology, alone considering specific, direct impacts.*

Market potential: The end-product contains several nutrients and could be competitive with mineral fertiliser given its concentration. P-recovery targets (DE) could be fulfilled.

End user acceptance: Easy to store and apply with existing machinery without risk of soil compaction. Scepticism due to sewage sludge origin.

Policy implications: Matches EU goals. EU FPR-compatible, but CE-marking too costly for the scale. Excluded from organic agriculture markets and lacks incentives.