BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits
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Closing the loop on nutrient losses from agriculture and cities
- a review of ecotechnologies, best practices, policies and economics, striving towards a more sustainable Baltic Sea Region

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x	PU	Public.
	PP	Restricted to other project partners.
	RE	Restricted to a group specified by the consortium.
	CO	Confidential, only for members of the consortium.

Contents

1   EXECUTIVE SUMMARY

This report is Deliverable 2.6 of the BONUS RETURN project and is part of WP2. This report refers to established and emerging technologies, business models and legislation that could facilitate the transformation of the agriculture and wastewater sectors towards a more circular economy for the Baltic Sea Region. It summarizes Tasks 2.1 to 2.3 which cover Deliverables 2.1 to 2.5, including:

1) a review of the published academic and grey literature for current ecotechnologies and practices for carbon and nutrient (phosphorus and nitrogen) recovery and reuse in municipal wastewater and agriculture. A total of 819 studies describing relevant technologies/practices were identified, 481 for wastewater and 338 for agricultural waste streams (Macura et al., 2018);

2) an overview of economic models used in evaluating the commercial viability of the ecotechnologies (Carolus, 2018);

3) an overview of policy instruments and governance structures affecting implementation of ecotechnologies (Barquet et al., 2019).

In the agricultural sector, ecotechnologies for recovery of nitrogen and phosphorus were more prevalent than for carbon recovery. The most common way of reusing carbon and nutrients was through manure-based ecotechnologies. Animal manure on its own is the principal source of recovery of nutrients or carbon. Among manure-based ecotechnologies, anaerobic digestion was the most frequent, followed by combinations/systems of technologies and struvite crystallization. The second largest group of studies was classified as 'mixed' which refers to manure mixed with plant biomass (e.g. crop residues). The most common ecotechnologies in this category were: composting/vermicomposting, pyrolysis/biochar production as well as anaerobic digestion/co-digestion. Two least frequent types of ecotechnologies were those relying only on plant biomass (e.g. crop residues) and those associated with water as the recovery source. Nitrogen recovery was overall slightly more common than phosphorus recovery, which in turn was significantly more common than carbon recovery.

For the wastewater sector, the body of evidence on ecotechnologies for energy recovery is larger than that of nutrient recovery, indicating that ecotechnologies for recovering energy are potentially more mature. The most common way of reusing nutrients is through biosolids or treated wastewater, both of which include organic carbon, nitrogen and phosphorus. Recovery of phosphorus is more common than nitrogen, especially when done through chemical processes. The higher representation of energy recovery over nutrient recovery, and of phosphorus recovery over nitrogen recovery, is in line with current paradigms within the wastewater sector.

The implementation and scaling up of technologies recovering and reusing nutrients and carbon is determined to a large extent by the global market price of phosphate rock, natural gas (for ammonia and biogas production) and other fuels and energy systems (for energy-based carbon and heat reuse) all of which ultimately affect the revenue and profitability of any technology. Strictly following the market costs and benefits, recovered nutrients must therefore be supplied with the same or lower market price to be economically feasible. Of course, there are significant societal drivers that go beyond just market drivers. The need to increase sovereign sources of phosphorus is a driver that promotes reuse of P. Another significant driver that affects the reuse of organic material in both agriculture and wastewater is the need to close the loop on carbon in order to reduce greenhouse gas

emissions. Also, the banning of ocean dumping and landfills for the disposal of sludge and manure has created new drivers for extraction of nutrients and reuse.

The report also summarizes the policy and governance structures that could facilitate or impede the transformation of the agriculture and wastewater sectors towards a more circular economy.

Although the Circular Economy Package has been adopted by the European Parliament in 2018, most EU policies and regulations are still dominated by linear resource-waste thinking and not circular economy concepts. Priority areas for changing this are packaging, plastics and climate-related measures. Phosphorus has yet to be included in the EU Nitrates Directive in order to better harmonize the reuse of P with N in agriculture systems. HELCOM works under the umbrella of the EU as a regional coordination body that produces recommendations on nutrient emissions from each member country as well as recommendations to promote best practices in order to recycle nutrients. Implementation is carried out by national governments. As a result, phosphorus recycling within the EU and the Baltic Region is governed by fragmented decision-making in regional administrations. Active regulatory support, such as recycling obligations or subsidies, is lacking in most countries. Legislation harmonisation, inclusion of recycled phosphorus in existing fertiliser regulations and support of new operators would speed up market penetration of novel technologies, reduce phosphorus losses and safeguard European quality standards.

2   INTRODUCTION

The degradation of the Baltic Sea is an ongoing problem, despite investments in measures to reduce external inputs of pollutants and nutrients from both diffuse and point sources. Available technological and management measures to curb eutrophication and pollution flows to the sea have not been adapted adequately to the contexts in which they are being applied. Furthermore, measures are often designed based on single objectives, thereby limiting opportunities for multiple benefits.

In addition, there is a general sense that measures to address the deterioration of the Baltic ecosystem are primarily technologically-driven and lacking broader stakeholder acceptance – the "experts" who define these measures have little engagement with industry, investors, civil society and authorities. This problem is magnified by governance and management, taking place in sectoral silos with poor coordination across sectors.

As a result, research shows that regional institutional diversity is presently a barrier to transboundary cooperation in the Baltic Sea Region (BSR) and that actions to achieve national environmental targets can compromise environmental goals in the BSR (Powell et al. 2013). The regional dimension of environmental degradation in the BSR has historically received weaker recognition in policy development and implementation locally. However, developments in recent years suggest a new trend with growing investments in environmental protection supporting social, economic, and territorial cohesion.

The BSR is an environmentally, politically and economically significant region and like other regions globally, its rapid growth needs to be reconciled with the challenges of sustainable development in a global setting that demands unprecedented reductions in GHG emissions. This poses a truly wicked problem exacerbated by the fact that many of the challenges in the BSR will also magnify in a changing climate. In order to navigate the uncertainties and controversies associated with a transformation towards a good marine environment, BONUS RETURN will enact an innovative trans disciplinary approach for identifying and piloting systemic eco-technologies.

The focus is on eco-technologies that generate co-benefits within other interlinked sectors, and which can be adapted according to geophysical and institutional contexts. More specifically, emphasis is placed on eco-technologies that reconcile the reduction of present and future eutrophication in marine environments with the regional challenges of policy coherence, food security, energy security, and the provision of ecosystem services.

2.1   Project Objectives

The **overall** aim of BONUS RETURN is to improve the adaptation and adoption of eco-technologies in the Baltic Sea Region for maximum efficiency and increased co-benefits.

The **specific objectives** of the project can be divided into six categories presented below. These categories are interlinked but for the purpose of providing a step-wise description, the following overview of each category proves useful. BONUS RETURN is:

1) **Supporting innovation and market uptake of eco-technologies by:**
   - Contributing to the application and adaptation of eco-technologies in the BSR through an evidence-based review (systematic map) of the developments within this field.

- Contributing to the development of emerging eco-technologies that have the capacity to turn nutrients and carbon into benefits (e.g. bio-energy, fertilizers), by providing an encompassing framework and platform for rigorous testing and analysis.
- Developing decision support systems for sustainable eco-technologies in the BSR.
- Contributing to better assessment of eco-technology efficiency via integrated and participatory modelling in three catchment areas in Finland, Sweden and Poland.
- Contributing to methodological innovation on application and adaptation of eco-technologies.

2) **Reducing knowledge gaps on policy performance, enabling/constraining factors, and costs and benefits of eco-technologies by:**
- Assessing the broader socio-cultural drivers linked to eco-technologies from a historical perspective.
- Identifying the main gaps in the policy environment constraining the implementation of emerging eco-technologies in the catchments around the Baltic Sea.
- Informing policy through science on what works where and under which conditions through an evidence-based review (systematic map and systematic reviews) of eco-technologies and the regional economic and institutional structures in which these technologies evolve.

3) **Providing a framework for improved systematic stakeholder involvement by:**
- Developing methods for improved stakeholder engagement in water management through participatory approaches in the case study areas in Sweden, Finland and Poland.
- Enacting a co-enquiry process with stakeholders into opportunities for innovations in eco-technologies capable of transforming nutrients and pollutants into benefits for multiple sectors at different scales.
- Bringing stakeholder values into eco-technology choices to demonstrate needs for adaptation to local contexts and ways for eco-technologies to efficiently contribute to local and regional developments.
- Disseminating results and facilitating the exchange of learning experiences, first within the three catchment areas, and secondly across a larger network of municipalities in the BSR.
- Establishing new cooperative networks at case study sites and empowering existing regional networks by providing information, co-organizing events and engaging in dialogues.

4) **Supporting commercialization of eco-technologies by:**
- Identifying market and institutional opportunities for eco-technologies that (may) contribute to resource recovery and reuse of nutrients, micro-pollutants and micro-plastics (e.g. renewable energy).
- Identifying potential constraints and opportunities for integration and implementation of eco-technologies using economical models.
- Facilitating the transfer of eco-technologies contributing to win-win solutions to multiple and interlinked challenges in the BSR.
- Linking producers of eco-technologies (small and medium enterprises – SMEs), to users (municipalities) by providing interactive platforms of knowledge exchange where both producers and users have access to BONUS RETURN's envisaged outputs, existing networks, and established methodologies and services.

5) **Establishing a user-driven knowledge platform and improved technology-user interface by:**
- Developing an open-access database that maps out existing research and implementation of eco-technologies in the BSR. This database will be intuitive, mapped out in an interactive

geographical information system (GIS) platform, and easily managed so that practitioners, scientists and policy-makers can incorporate it in their practices.

- Developing methodologies that enact the scaling of a systemic mix of eco-technological interventions within the highly diverse contexts that make up the BSR and allows for a deeply interactive medium of knowledge.

2.2 Project Structure

BONUS RETURN is structured around six Work Packages that will be implemented in three river basins: The Vantaanjoki river basin in Finland, the Słupia river basin in Poland, and Fyrisån river basin in Sweden.

Work Package 1: Coordination, management, communication and dissemination.
Work Package 2: Integrated Evidence-based review of eco-technologies.
Work Package 3: Sustainability Analyses.
Work Package 4: Environmental Modelling.
Work Package 5: Implementation Support for Eco-technologies.
Work Package 6: Innovative Methods in Stakeholder Engagement.

2.3 Overview of Work Package 2

The aim of WP2 (consisting of Tasks 2.1, 2.2 and 2.3 - see below for details) is to systematically collate scientific research of existing and emerging ecotechnologies, as well as the economic models and policy instruments that support the implementation and development of these technologies in the BSR countries. This includes the grey literature such as government papers and organizational reports, along with theses, conference proceedings and commercial publications. Specifically, the systematic map collates and describes existing research for ecotechnologies across the BSR, leading to the following outputs that also feed into other work packages within the BONUS RETURN Project:

- A comprehensive list of studied ecotechnologies from the literature relevant to the BSR.
- A description of all studies that have investigated these ecotechnologies
- An assessment of 'knowledge gaps' where known ecotechnologies are unrepresented or underrepresented in the published (grey and traditional academic) literature
- An assessment of 'knowledge clusters' where sufficient reliable evidence exists to allow full systematic review and meta-analysis
- A list of existing reviews that focus on the effectiveness of single or multiple ecotechnologies

Following systematic mapping including input from stakeholder platforms, one or more eco-technologies are taken forward to full systematic review and meta-analysis, allowing quantitative summaries to be produced that can be used to validate analyses in WP3 and models in WP4. Prioritisation and selection of ecotechnologies to fully synthesise with meta-analysis are undertaken in consultation with BONUS RETURN consortium stakeholders via WP6.

2.3.1 *Description of Tasks 2.1 to 2.3 within WP2*

Task 2.1 Systematic maps of studied ecotechnologies
Two systematic maps were undertaken according to existing guidance (CEE, 2014). Both grey and academic literature were included where relevant, with a focus on ecotechnologies in the Baltic Sea

Region (BSR) countries. The aim of the maps was to collate evidence on ecotechnologies for recovery and reuse of carbon, nitrogen and phosphorus from domestic wastewater and agricultural waste streams (Haddaway et al 2019a, b). Due to the importance of grey literature and non-English language evidence, searches for grey literature were performed in three Baltic languages (Polish, Swedish and Finnish) using web-based search engines and searches of specialist organisational websites. From the systematic maps, WP2 in conjunction with WP3, aim to select the most relevant ecotechnologies according to the following criteria where ecotechnologies:

● Produce co-benefits to society in the form of economic gains, human well-being or multi-sector gains
● Can be used to reduce both nutrient enrichment and transport of organic matter especially from arable land
● Can potentially be integrated into existing local and regional systems and use existing processes and resources, to ultimately produce integrated technologies which
  ○ have already been implemented and there are available data for testing them through both environmental models (indicators related to technologies' biological efficiency) and through sustainability analyses (social and economic indicators) or
  ○ emerging ecotechnologies that have not generated any data yet but have gone through rigorous investigative processes, can present theoretical evidence of sustainability, but are in need of further assessments and better linkage to municipalities and potential markets (for a more detailed description see WP5)

This selection is also developed in consultation with local stakeholders in the three case study sites (through WP 6), and the outcome of these consultations are the basis for analyses in WP3, WP4 and WP5.

Task 2.2 Full systematic review and meta-analysis of effectiveness
Following on from the completion of the systematic map described in T 2.1, one or more ecotechnologies (depending on the volume of available evidence) are selected through consultation and prioritisation with the project consortium and other stakeholders. The evidence relating to these ecotechnologies are then taken forward to full systematic review according to established guidelines (Higgins and Green 2011; CEE, 2014). These reviews include critical appraisal of all studies, extraction of relevant quantitative data, and meta-analysis to produce summary effect sizes for each ecotechnology (accounting for key sources of heterogeneity).

Task 2.3 Review of economic models, policy instruments and governance structures
A review relating to economic models, policy instruments and governance structures was carried out in order to find regulatory tools and incentives that could affect deployment of ecotechnologies and utilization of the reuse products in the BSR.

2.3.2 *List of the summarized deliverables in this report*

D 2.1: The training on systematic review and mapping methodology was provided through an intensive 2-day workshop aimed at providing participants from partner organizations with the necessary skills and experience in undertaking the practical activities that form part of a systematic map or review, including searching, screening, critical appraisal, data extraction and meta-analysis. The training was provided according to international systematic review standards set out by the Collaboration for Environmental Evidence (CEE, 2014) and provided by a CEE-endorsed trainer (Neal Haddaway, SEI).

D 2.2: List of ecotechnologies. Assessment of full text articles from the systematic mapping exercise allowed for a comprehensive list of ecotechnologies to be compiled from the literature. This list was added to in an iterative process for use in WPs 3, 4 and 5 and completed after month 10 of the Project.

D 2.3: An interactive, searchable database of research on ecotechnologies for the BSR was produced (the two systematic map databases) to accompany the systematic map report (a document describing the state of the evidence identified, including the identification of knowledge gaps (Macura et al., 2018)). Additionally, the systematic map database was mapped cartographically via an online open access, interactive geographical information system (GIS) allowing stakeholders to identify research conducted across the BSR and extract metadata describing the research and the ecotechnologies investigated. The systematic map database was used as a basis for identifying one or more ecotechnologies for which sufficient reliable evidence exists to allow a full systematic review and meta-analysis. The list of meta-analysable subtopics were subject to selection and prioritisation through contact with stakeholders to ensure that the most relevant and topical subjects were synthesised.

D 2.4: A systematic review of economic models and instruments supporting or obstructing the implementation and development of the selected ecotechnologies. This review (Carolus, 2018) increased understanding of how particular economic models have affected the choice of the ecotechnologies from a historical point of view to date. The review throws light on whether particular economic models have had theoretical or empirical appeal for adoption of an ecotechnology, the social-economic impacts of the technology at catchment /sub-catchment and regional levels, the cost-effectiveness dimension of these ecotechnologies, and the policy instruments and incentives employed to trigger their adoption.

D 2.5 - A review of the policy instruments and governance structures in the BSR. This report (Barquet et al., 2019) sheds light onto the major policy trends affecting the choice, implementation and development of ecotechnologies from historical and current perspectives. The review highlights how particular policies and institutional arrangements have either facilitated or hampered the adoption of ecotechnologies, the implications of such policies for the region, and the political incentives adopted to trigger their use.

2.4   Outline of the report

This report provides an overview of the findings from the BONUS RETURN published Deliverables 2.1 to 2.5 within WP2. A background section is provided describing the current situation of the Baltic Sea and the justification for the BONUS RETURN project. Deliverables 2.3, 2.4 and 2.5 are summarized in the following 3 sections of the report. This includes the results of mapping of literature on ecotechnologies for reuse and recovery of carbon and nutrients, overview of economic models and overview of relevant policy instruments and governance structures within the Baltic Sea Region. The discussion section covers insights into the need for further sharpening of today's nutrient management policies in order to further promote reuse of carbon, nitrogen and phosphorus. The report then provides a conclusion section followed by the list of references.

3 CLOSING THE LOOP ON NUTRIENT LOSSES FROM AGRICULTURE AND CITIES - A REVIEW OF ECOTECHNOLOGIES, BEST PRACTICES, POLICIES AND ECONOMICS, STRIVING TOWARDS A MORE SUSTAINABLE BALTIC SEA REGION.

3.1 Background

Wastewater has been traditionally seen as a waste requiring treatment in order to reduce negative impacts before it is released into the receiving water system (Andersson et al., 2016). Content such as organic carbon (C), nitrogen (N) and phosphorus (P) have been seen as water pollutants and treatment systems have been set up to render the released water less a pollutant. Phosphorus was traditionally removed using flocculating agents like aluminium sulphate or iron sulphate and iron chloride (Yeoman et al., 1988). The sludge arising from this process isn't easily available to crops in agriculture so alternative processes have been developed such as calcium hydroxide (lime) precipitation of phosphorus and biological uptake of phosphorus by activated sludge. Also, addition of magnesium compounds (sulphate, oxide, hydroxide) has become popular in order to produce struvite which contains both N and P (Forrest et al., 2008). Excess nitrogen in wastewater has been reduced to volatile nitrogen gas by exploiting the biological process denitrification which occurs under anaerobic conditions (Lu et al., 2014). These processes result in potential reuse products such as sludge which contains P as well as struvite crystals which contain phosphorus, nitrogen and magnesium.

Common practice in agriculture (Tybirk et al., 2013; Audette et al., 2016; Pintoa et al., 2017) shows there is value in reusing the "waste" products arising from farming such as manure, crop residues, other organic materials and leachates. Farmers are also interested in optimizing crop yields and key on nitrogen content of the manure, slurry or compost that is being spread onto fields. These compounds usually have N/P ratios lower than the crop needs, so in order to try to better match the nitrogen requirements of the crops, excessive amounts of P end up being applied to fields. This excess P is absorbed by most soils and can result in saturation of the upper layers after several years (McCrackin et al., 2018). Annual periods of runoff remove some of this excess P through soil erosion.

The Baltic Sea Region, home to some 80 million people has experienced a century of fertilizer overuse especially during 1950 to 1990 (McCrackin et al., 2018). Although the use of chemical fertilizers has decreased over the past 30 years in the Baltic Sea Region and wastewater treatment has significantly reduced point source emissions, the levels of dissolved- and total phosphorus (P) in the open sea continue to increase (Savchuck, 2018). The Baltic Sea is eutrophic and now shows signs of seasonal dystrophy with large-scale nerve-toxic cyanobacterial blooms and extensive oxygen-free sediments, a condition more common for smaller hypertrophic lakes. The cyanobacteria blooms (Fig. 1) continue to occur across the Baltic Sea Proper every summer in various scales and the deep holes remain anaerobic. This has had negative impacts on such things as fisheries and tourism (Ahtiainen et al., 2014).

Fig 1. Large-scale cyanobacteria blooms across the Baltic Sea (ESA, 2005) caused in part by hypoxia releasing phosphate from the bottom sediments. These algae are not nitrogen-limited since they can fix atmospheric nitrogen.

Sediment cores show that blue-green algal blooms have co-occurred in combination with benthic hypoxia in the Baltic Sea as far back as 7000-4000 B.C. (Funkey et al., 2014).

The explanation for the continued increase in phosphorus levels in the open water is two-fold: legacy P in the farmlands of the drainage basin from decades of additions of chemical fertilizer finds its way into the sea through runoff, and internal loading of P from the deep anaerobic sediments (McCrackin et al., 2018). Also spreading of manure on farmland based on nitrogen (N) crop requirements results in significant P overloading because manure contains relatively low N to P ratios. These loading sources are further aggravated by the fact that the Baltic Sea Proper is enclosed with a water residence time (time required for one volume change) of 25 to 40 years (Meier, 2005). Improvements in the water quality and degree of eutrophication are not occurring.

The BONUS RETURN project has been examining methods to trap P in runoff water and to reuse N, P and carbon compounds in land-based activities - before they are lost to overloading and runoff.

Some 4500 recently published (2013-2017) literature records were screened, finally resulting in the identification of 819 studies that describe several different wastewater and agriculture ecotechnologies and best practices. The project has also assessed the various drivers, barriers and regulations that affect the development of nutrient and carbon reuse. Indeed, the philosophy of a circular economy is at the core of these questions, but the EU directives, regional agreements and national legislation are rooted in controlling emissions from point sources like cities and large pig and poultry operations and setting limits to manure and fertilizer applications to farmland. Regulations encouraging closed looped nutrient systems are still in their infancy.

This report summarizes BONUS RETURN Deliverables 2.2 and 2.3 (mapping of academic and grey literature on ecotechnologies for reuse and recovery of carbon and nutrients), 2.4 (overview of economic models) and 2.5 (overview of relevant policy instruments and governance structures) within the Baltic Sea Region.

3.2 Overview of viable wastewater and agriculture ecotechnologies and practices

Deliverables 2.2 and 2.3 (Macura et al., 2018) of the BONUS RETURN project contain two systematic map reports (describing the state of evidence and knowledge gaps) accompanied by two searchable databases on ecotechnologies for carbon and nutrient recovery and reuse - one report for wastewater and one for agriculture. Additionally, this includes links to the two respective evidence atlases i.e. interactive cartographic representations of the mapped evidence. This allows stakeholders to visualise catalogued research on ecotechnologies for carbon and nutrient recovery and reuse from wastewater and agriculture and extract metadata describing the research and the ecotechnologies investigated.

The evidence base for wastewater ecotechnologies included 481 relevant articles, each describing one ecotechnology, or a combination of ecotechnologies, for recovering/reusing carbon, nitrogen or phosphorus from wastewater (Macura et al., 2018). The evidence base for ecotechnologies used in agriculture included 338 relevant studies describing one ecotechnology for recovering/reusing carbon, nitrogen or phosphorus from various sources in agriculture (Macura et al., 2018).

For the wastewater sector, the body of evidence on ecotechnologies for energy recovery is larger than that of nutrient recovery, indicating that ecotechnologies for recovering energy are potentially more mature. The most common way of reusing nutrients is through biosolids or treated waste-water, both of which include organic carbon, nitrogen and phosphorus. Recovery of phosphorus is more common than nitrogen, especially when done through chemical processes. The higher representation of energy recovery over nutrient recovery, and of phosphorus recovery over nitrogen recovery, is in line with current paradigms within the wastewater sector.

In the agricultural sector, ecotechnologies for recovery of nitrogen and phosphorus were more pre-valent than for carbon recovery. The most common way of reusing carbon and nutrients was through manure-based ecotechnologies. Animal manure on its own is the principal source of recovery of nutrients or carbon, with such publications constituting the majority of the evidence base. Among manure-based ecotechnologies, anaerobic digestion was the most frequent, followed by combinations/systems of technologies and struvite crystallization. The second largest group of studies was classified as 'mixed' which refers to manure mixed with plant biomass (e.g. crop residues). The most common ecotechnologies in this category were composting/vermicomposting, pyrolysis/biochar production as well as anaerobic digestion/co-digestion. Two least frequent types of ecotechnologies were those relying only on plant biomass (e.g. crop residues) and those associated

with water as the recovery source. Nitrogen recovery was overall slightly more common than phosphorus recovery, which in turn was significantly more common than carbon recovery.

It is noteworthy to mention that most current environmental and water policies focus on reduction of pollution from different waste streams rather than on recovery and reuse of nutrients. Such 'conventional' measures do not, however, belong to this study. Instead, this report provides an unbiased and comprehensive evidence base on nutrient recovery and reuse that can be expected to gain much importance in the Baltic Sea Region in coming years.

Table 1 provides a selection of both common and developing ecotechnologies and practices found in the Baltic Sea Region within the agriculture and wastewater sectors.

Table 1. Selection of both common and developing ecotechnologies including best practices for nutrient reuse (based on Macura et al., 2018)

Technology/practice	Brief description	Advantages
Agricultural Applications		
Sustainable manure spreading on farmland	Manure from cattle, pigs and poultry added to cropland using sustainable methods	The most significant form of nutrient reuse in the Baltic Sea Region (Tybirk et al., 2013)
Sustainable agricultural practices	Timing and method of manure and fertilizer application; choice of tillage; crop rotations that reduce transport losses	Grass cover crops have been shown to prevent nitrogen (N) leaching to groundwater by accumulating excess soil N. Autumn early-planted cover crops showed greater ability to recover residual soil N before the onset of potential N leaching events during fall and winter months (Komatsuzaki, 2015)
Biogas from cattle manure	Biogas production using anaerobic digestion of manure	Can be economically beneficial depends upon the manure quantity, transportation distance, dry content, manure price and manure discharge price (Yazan et al., 2018)
Ammonia stripping and vacuum evaporation of manure	Nitrogen and phosphorus recovery from manure through ammonia stripping and vacuum evaporation	Can be used as an alternative for nutrient recovery and concentration. The achieved liquid digestate after vacuum evaporation with high nitrogen and phosphorus content can be conveniently transported and used during planting season. The achieved liquid digestate after ammonia stripping with low nitrogen and phosphorus content is appropriate as irrigation water to improve soil structure and water holding capacity during winter (Li et al., 2016)
Struvite precipitation of manure liquid fraction and wastewater	Struvite precipitation from WWTP/ in swine slurries or batch reactors (Taddeo et al., 2015)	Substitute struvite for conventional mineral-P fertilizer. Added-value gains for WW facilities (Taddeo et al., 2015)

Utilization of existing soil P reserves to reduce legacy P	Breeding of more P-efficient crops and engineering microbes to better mobilize soil P	Total P reduction through recovery of ever-smaller sized particles was 40-50%, giving a system P removal rate of 50-65% (Ma et al., 2013)
Vermicomposting of organic material	Vermicomposting of manure, sludge and organic solid waste	Vermicompost is one of the highest-grade and most nutrient-rich (nitrogen, potassium, phosphorus, calcium) natural organic fertilizers. (Garcia-Sanchez et al., 2017)
Composting of organic material (farm wastes and manure)	Reuse of nutrients from farm wastes and manure as fertilizer to croplands	Better plant growth in soil fertilized with compost than without. Net transformation/plant uptake of the labile/moderately labile P was faster too (Audette et al., 2016). The slowly released N of farmyard compost increased crop yields, with lower risk of N loss (Pintoa et al., 2017)
Thermal treatment of sludge and manure	Hygienization of sludge and manure by heating to higher than 60°C using external heat source	Ease of scaling up, chemical-free separations, low operating and maintenance costs, compact and modular design and highly selective separations (Gerardo et al., 2015)
Urea hygienization of manure	Added urea reduces to ammonia which in turn kills bacteria in the manure	The urea is an agent of hygienization and is itself a nutrient when the mixture is added to soil, thus increasing the nitrogen content (Stiegler et al., 2013)
Buffer strips and sedimentation ponds	Planting of perennial grass, shrubs and trees to trap soil and reduce erosion and runoff losses; use of small sedimentation ponds to trap suspended soil in runoff	Common practices to intercept soil and nutrient loss and reduce transport to surface water (Noij et al., 2013)
Adsorption of nitrogen and/or phosphorus from water	Nitrogen and phosphorus removal from water using surface modification of adsorbents	Nitrate adsorption has shown to have a high adsorption capacity, which was reported to be approximately equal to that of a commercial anion exchanger (Loganathan et al., 2013)
Wastewater Applications		
Sludge stabilisation	Stabilisation ponds as wastewater treatment technology	Organic matter is removed from the wastewater, pH increases and oxygen levels in the effluent increase to near saturation levels (8 mg O_2/L) (Faleschini & Esteves, 2017).
Sludge hygienization	Reduction in pathogens in sludge using heat and urea	See Gerardo et al., 2015 and Stiegler et al., 2013 above
Sludge spreading on farmland	Sludge from wastewater treatment spread as a soil amendment and fertilizer on farmland	The nitrogen and phosphorus increase in the soil from spread sludge on farmland. Part of the phosphorus binds with iron and other constituents in the sludge (Nielsen & Wilson Bruun, 2015)

Incineration of sludge followed by phosphate extraction	Incineration of sewage sludge to recover P using acid extraction	Highest recovery potential of P from sludge. (Easy Mining (Mayer et al., 2016)
Anaerobic membrane bioreactors with algal cultivation	Water and nutrient recovery from microalgal cultivation in outdoor photobioreactors using the effluent from an anaerobic membrane bioreactor fed with pre-treated sewage	High quality water recovery from sewage effluent (Viruela et al., 2016)
Irrigation with treated wastewater	Wastewater pumped onto cropland for irrigation and fertilization	Common practice in low-income countries in peri-urban areas is to irrigate with untreated wastewater. (Drechsel and Evans, 2010; Drechsel et al., 2010; Ramdhanie et al. 2010)
Up-flow anaerobic sludge blanket reactor for biogas production	Hybrid anaerobic sludge blanket reactor at a water treatment facility for the biodegradation of distillery spent wash and domestic waste to produce biogas and energy	The construction was found to be a lucrative and sustainable venture (Ramdhanie et al., 2014)
Algal-based biochar	Method to bind nutrients into microalgae and then produce biochar for addition to cropland	Algal biochar produced through slow pyrolysis at 450C and then added to composted algae/sugarcane. The biochar binds N and P better and can increase crop productivity. It increased corn productivity by 15% (Cole et.al. 2017)
Microalgae for wastewater treatment	Microalgae offer the potential to remove and recover nutrients (N and P) from waste streams and subsequently use the microalgal biomass as a sustainable low-release fertilizer or as a source of other products like biodiesel	The microalgae *Botryococcus braunii* contains a relatively high content of hydrocarbon which can be used for the production of biodiesel. The satisfactory removal of N and P (more than 65 and 95%, respectively) was obtained in short retention times of 4 days. (Gokulan et al., 2013; Diniz et al. 2017)
Biochar from digested sludge	Biochar made from anaerobically digested sewage sludge	Recovery and reuse of P from sewage sludge transformed to biochar and then used as fertilizer. Addition of ochre to the feedstock not only improves P recovery properties, but also produces biochar which comply with guidelines relevant to possible future regulation of biochar application to soil. (Shepherd et al., 2016; Zielinska et al., 2016)
Source-separation of grey and blackwater in sewage systems	Source-separated greywater from kitchen/washing facilities is treated locally while the notably higher polluted blackwater from toilets is collected and transported to a centralized treatment or recovery facility	Significant reductions for COD, BOD, TSS, N and P (Moges et al., 2017)

P adsorption from wastewater using heat treated oyster shells	Phosphate removal to hydrothermally modified silica and pulverized oyster shell material for use in wastewater treatment	The oyster shell material acts as an effective adsorbent for phosphate removal from wastewater. Equilibrium is obtained rapidly within 48 hrs with removal ratio exceeding 90% (Chen et al., 2013)
Septic tank and infiltration for local sanitation systems	A novel two-stage system consisting of a trickling filter and a multi-soil-layering (MSL) bioreactor for enhanced treat-ment of domestic wastewater from decentralized sources	Operates well for COD removal and nitrification (nitrate production) with little management and labour demand (Luo et al., 2014)
Microbial electrolysis cells	Degradation of organic matter in wastewater into volatile fatty acids and ethanol by using electrolysis cells	Microbial electrolysis cells system has the potential for higher COD removal rate and hydrogen production together from anaerobic baffled reactor (Wu et al. 2013)
Microbial fuel cells	Microbial fuel cells (MFCs) are devices that use bacteria from wastewater as the catalysts to oxidize organic and inorganic matter and to produce electrical current	The organic matter removal efficiency was up to 80% (Buitrón & Cervantes-Astorga, 2013)

3.2.1   *Wastewater technologies*

A cartographic map was produced including locations of ecotechnologies (Figs. 2 and 3)[1], based on the evidence base. The evidence atlas is interactive and can be searched for specific cases and descriptive information about each study using a visual interface and accompanying data table. Articles that did not include any study location are not displayed in the evidence atlas (a total of 132 articles).

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[1] https://drive.google.com/open?id=1_S1B21E5opoX5LCZU3VPxvTmdRV1Ark0&usp=sharing

Fig 2. Global evidence atlas for ecotechnologies reusing nutrients and carbon related to the wastewater sector (derived from Macura et al. 2018).

Fig 3. Evidence atlas for ecotechnologies reusing nutrients and carbon related to the wastewater sector in the Baltic Sea Region (derived from Macura et al., 2018).

The "Treatment process" categories identified in the evidence include:

- Biological treatment: ecotechnologies based on biological processes, for example, cultivation of microalgae, anaerobic digestion, composting and productive wetlands.
- Biochemical treatment: ecotechnologies based on the microbial conversion of chemical energy to energy, such as microbial fuel cells (producing electricity) or microbial electrolysis cells (producing hydrogen).
- Physicochemical treatment: ecotechnologies based on, for example, the selective separation

of particles from the wastewater using membranes or sorption of selected substances into another substance such as adsorption or ammonia stripping.

- Chemical treatment: ecotechnologies based on the chemical precipitation of a substance from the wastewater, for example through acidification, alkalinisation or addition of chemicals to precipitate nutrients in solid form, such as struvite.
- Thermochemical treatment: ecotechnologies based on various heat transformation processes such as pyrolysis, gasification, combustion and hydrothermal processes.
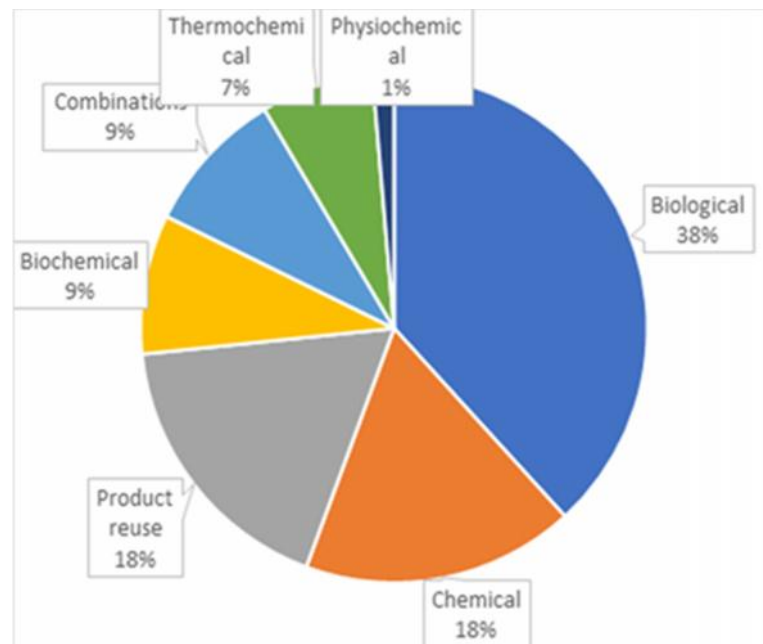
Fig. 4. Distribution of articles coded with explicit reuse in the categories: 'biological', 'chemical', 'physicochemical', 'thermochemical', 'product reuse', 'biochemical' or a "combination" in the evidence base of ecotechnologies in the wastewater sector (from Macura et al., 2018).

As seen in Fig. 4, most ecotechnologies in the evidence base (481 technologies) were classified as biological processes (38%). Chemical processes represented 18%. Studies identifying specifically "product reuse" represented 18% of the total. The majority of the articles in the product reuse group describes use of biosolids or treated wastewater as fertilizer. Both of these reuse products are most frequently the result of biological treatment processes. The most frequent biological process described in the mapped literature - anaerobic digestion - also has potential for energy recovery in the form of biogas. Combinations of treatment processes represent 10% of the evidence base. The most common combination was biological and physicochemical, mainly anaerobic membrane bioreactors.

3.2.2 Agri-technologies

As in the case of the wastewater map, an atlas was produced for the locations of the agriculture ecotechnologies (Figs. 5 and 6)[2]. Studies that did not include any location (175) are not displayed in the evidence atlas.
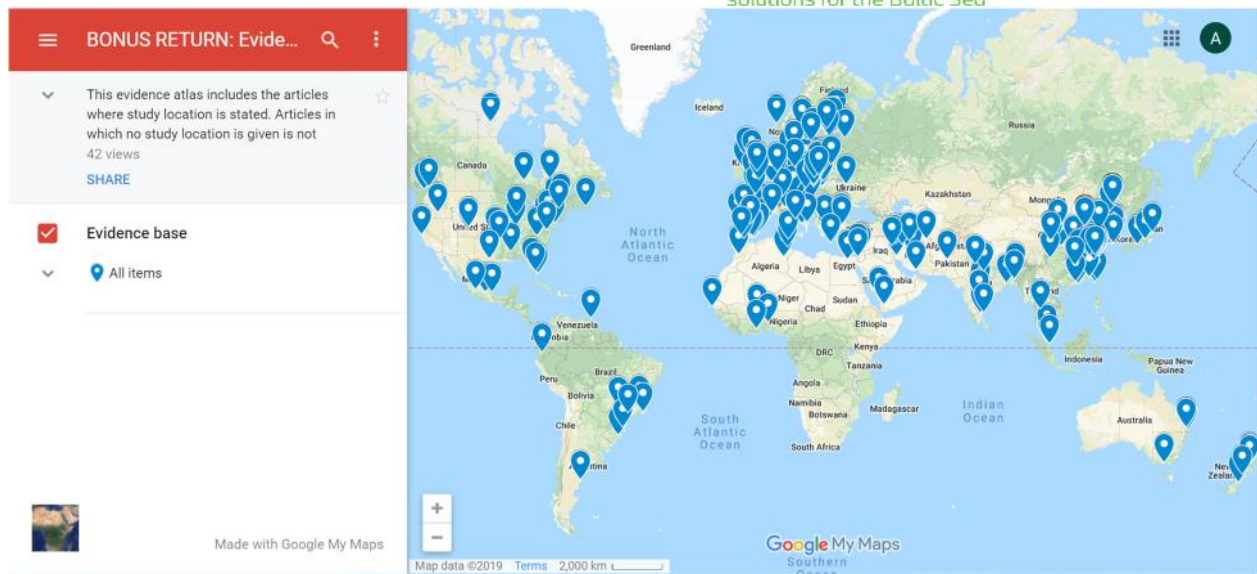

Fig 5. Global evidence atlas for ecotechnologies reusing nutrients and carbon related to the agriculture sector (derived from Macura et al., 2018).

Fig 6. Evidence atlas for ecotechnologies reusing nutrients and carbon related to the agriculture sector within the Baltic Sea Region (derived from Macura et al., 2018).

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[2] https://drive.google.com/open?id=1jBq6NOHophcfojzqxJIL90MfsX2GdzmL&usp=sharing
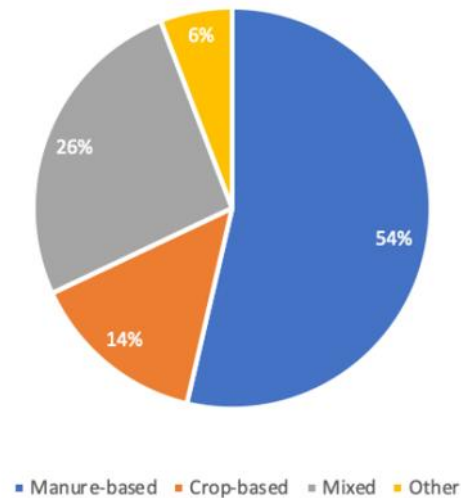
Fig 7. Percent of different types of ecotechnologies included in the evidence base for agriculture (from Macura et al., 2018).

The included ecotechnologies (338 in total) were classified into 4 different categories (Fig. 7) with respect to the source of recovered nutrients or carbon i.e. manure-based (183 studies), crop-based (49), mixed (89) and other (17).

The most prevalent ecotechnologies in the evidence base for agricultural ecotechnologies were manure-based (Fig. 7). Manure is the principal source for recovery of nutrients or carbon, constituting 54% of the evidence base. Among manure-based ecotechnologies, anaerobic digestion/co-digestion was the most frequent, followed by combinations/systems of technologies and struvite crystallization. Other typical ecotechnologies in this group were solid-liquid manure separation, air stripping, composting/vermicomposting and manure drying. Various types of manures, swine, poultry, cattle, horse, etc. were reported as a recovery source, but some studies did not specify manure type. Another division of manure was into solid and liquid, without specification of the source animal species.

3.3   Review of economic models and instruments

In D 2.4, a review of economic models and instruments (Carolus, 2018) was carried out for the ecotechnologies which were selected in the three BONUS RETURN empirical case areas (Słupsk in Poland, Vantaanjoki in Finland, and Fyris in Sweden). The review aimed to increase the understanding of which and how particular economic models assess ecotechnologies, and to shed light on both the benefits and costs of adoption of selected ecotechnologies, the social and private components of those costs and benefits, and which incentives may trigger or hinder their adoption.

Generally, the review revealed an increasing quantity of economic literature on ecotechnologies during the past six years (2013-2018), with the major share of studies focusing on private sector costs related to implementing and maintaining a specific technology. While Cost-Benefit Analysis (CBA) is the foremost applied model, there is no consensus on how CBAs are to be conducted here (e.g. in terms of which impacts to include or neglect).

The implementation of technologies recovering and reusing phosphorus, nitrogen or carbon is determined by the global market price of phosphate rock and methane gas (for ammonia and carbon reuse) all which ultimately affects the revenue and profitability of any reuse technology (Carolus, 2018; Schipper, 2019). Recovered P therefore competes against an industry characterized by huge volumes and optimized technology. Investments in ecotechnologies may therefore be inappropriately high. To stimulate interest, competitions or prizes have been offered to introduce new technologies e.g. the Baltic Sea Nutrient & Carbon Reuse Challenge in context of the BONUS RETURN project, or the George Barley Water Prize (2018).

3.3.1 *Drivers and barriers*

Different drivers and barriers determine a successful and beneficial management shift towards nutrient and carbon recovery and reuse technologies. Returning to the definition of Haddaway et al. (2018), such technologies are referred to as ecotechnologies describing "human interventions in social-ecological systems in the form of practices and/or biological, physical, and chemical processes designed to minimise harm to the environment and provide services of value to society". From an economic perspective, recovery and reuse technologies may be identical yet the outputs are handled differently. Recovery implies removal of, for instance, P from wastewater, whereas reuse refers to feeding the recovered product back into a market (e.g. selling recovered P as fertiliser). While a recovered product may therefore result in indirect and/or social benefits such as avoided costs due to reduced pollution (e.g. eutrophication), a reuse product generates additional direct or indirect cash flows, e.g. when sold in a market. Pearce (2015) categorises the drivers and barriers of implementing reuse-oriented technologies into economic, environmental, technical, regulatory, organisational and individual. Table 2 provides an overview of some of the economic barriers and drivers for recovery and reuse of phosphorus.

Table 2. Overview of economic drivers and barriers (from Carolus, 2018)

	Economic drivers and barriers for implementing nutrient recovery			
	Cost of technology and production cost	**Market demand for recovery products**	**Market price**	**Transportability**
P recovery/ reuse	Recovery cost likely to exceed market value of the outputs; indirect savings due to heat or electricity reuse; social benefits are likely to reveal externalities	Market demand is given for most products (possibly only after further treatment); legislative frameworks often insufficient due to not classifying recovered products with similar characteristics as commercial alternatives	Production costs likely to exceed market value of mined and processed P	Important but an often unconsidered or secondary condition. Results depend on the specific technology and product, for instance incineration products have a lower weight

While different drivers and barriers exist, the most important decision criterion leading to the implementation of an ecotechnology is its economic feasibility (Pearce, 2015; Roy, 2017; Schipper, 2019). However, if a project is considered economically feasible this depends on the perspectives,

intentions and assessment frameworks. In particular, economic feasibility may be understood differently by operating actors and investors ("should I invest in/implement the ecotechnology?"), or from the viewpoint of a decision-maker considering society as a whole ("is overall social welfare increasing when spending tax money on stimulating ecotechnologies?"). The environmental and welfare economic disciplines therefore distinguish between private and social costs and benefits. Although private and social costs and benefits are sometimes identical, the market price often does not reflect this.

3.3.2 *Private vs public sector actors*

For a privately operating actor or investor, economic feasibility is therefore usually understood as private benefits exceeding private costs, whereas the relevant criterion for the viewpoint of society is that social benefits outweigh social costs. The central elements of the BONUS RETUR project are typical and relevant examples leading to negative externalities (i.e. the social and private costs are dissimilar), namely the emissions of carbon, nitrogen or phosphorus. A special case for decision-making with respect to implementing ecotechnologies is if regulations are in place, as P recovery in e.g. Switzerland and Germany (Schipper, 2019). The question would then move to how a set target or regulations can be achieved or fulfilled in the best (e.g. cheapest) manner. Low or moderate investment and operation costs are identified as one success criterion of implementing ecotechnologies. In turn, high cost (e.g. due to a costly use of chemicals and energy, or when generating additional waste streams which need to be disposed of) may pose barriers, in particular if combined with an uncertain potential for market revenues.

Within the context of reuse technologies (i.e. with the intention to reuse the recovered outputs), an existing market, i.e. a source for expected income and profit, is another central economic element determining the adoption ecotechnologies of some operating actor or investor (Mayer et al., 2016; Pronk & Koné, 2009). In other words, the "ability to generate a product with a clearly defined market potential" is essential (Schipper, 2019). However, not only the existence of a suitable market, but also the expected market prices (for both the new and comparable products) matters. If the market prices are volatile or uncertain, the expected revenues decrease. Without prospects of profits, actors or investors may consequently abstain from too high cost and invest in other markets. Even if some technology is tested for many years, the limited scale of production may result in (too) high costs per recovered unit (Fam & Mitchell, 2013). Furthermore, the difficulties in integrating recovery products into markets is best evidenced by the most straightforward reuse product of wastewater treatment plants (WWTP), namely water. Amongst other barriers, Sanz & Gawlik (2014) identify a lack of financial incentives and poor business models as obstacles for a more extensive application of water reuse strategies in Europe.

Furthermore, while not implying a positive cash flow, indirect benefits may increase the economic feasibility of some systems or technologies, even if the resulting outputs would not be feasible at markets. For instance, struvite recovery is typically too costly to compete with the mined alternative, yet its recovery may reduce the damage in valves and pipes (Mayer et al., 2016; Rao et al., 2015). Moreover, additional technologies may increase the investment costs but decrease the overall costs, for instance when covering the heat and electricity requirements of the process (Murashko et al., 2018).

Finally, changes in utility are not directly measurable. For instance, the degree to which a reduction in eutrophication makes a population better off cannot be measured in monetary values in a straight forward manner. Economists therefore draw on monetary proxies, namely the populations'

willingness-to-pay (WTP) for some change to take place, or the willingness-to-accept (WTA) some change (Hanley & Barbier, 2009; Hanley et al., 2002).

3.3.3 *Overview of economic assessment methods used to assess reuse products in the BSR*

Techno-Economic Assessment (TEA)
Generally, TEA refers to the (typically ex-ante) assessment of some technology with the key purpose of setting a specific technology design in the context of its cost and performance, for instance in order to compare it to potential alternatives. While not explicitly restricted, TEAs commonly focus on the expected investment and ongoing cost of a technology in context of the quantified yet not monetarised outputs, such as the relative cost of CO_2 capture (Frey & Zhu, 2012), wastewater treatment (Singh et al., 2018) and/or digestate treatment (Bolzonella et al., 2018). A TEA can therefore be considered as technology-oriented, and rather refers to a recovery process, as this is usually not defined as having a market value.

Cost-Effectiveness Analysis (CEA)
Similar to TEA, CEA is conducted to provide a ranking of the relative performance of different technologies or measures. While this entails that CEA and TEA may consist of, de facto, the same content, CEA is usually more output-oriented. The approach thereby sets the cost of the technology in context of the associated physical effectiveness (Balana et al., 2011). The CEA thus expresses the cost per physical unit, e.g. € per ton of recovered P, enabling a direct economic ranking of different technologies.

Cost-Benefit Analysis (CBA)
Cost-Benefit Analysis (CBA) is a widely accepted method for evaluating policies and projects (Hanley & Barbier, 2009). CBA collects all costs and benefits of an intervention (e.g. a project, policy or measure) into a bottom-line, the net present value (NPV). From an economic point of view, interventions with positive NPVs should consequently be implemented. While originally only considering purely monetary values, the inclusion of social and/or environmental values into CBA were introduced in the 1980s (Molinos-Senante et al., 2010).

3.3.4 *Ecotechnologies that are commercially viable*

Recovery and reuse of P from wastewater
Mayer et al. (2016) calculate the cost (per capita/year), the recovery potential (kg P recovered/capita/ year) and the energy requirements (kWh/capita/year) of selected P recovery technologies. The technologies are thereby split into three groups:

  (A) Crystallisation processes applied to liquids from sludge dewatering (Airprex, PRISA, Crystalactor, and precipitation from sludge-free wastewater),
  (B) P recovery from incinerated sewage sludge ash (ASH-DEC and PASCH), and
  (C) P recovery from sludge (Seaborne and KREPRO).

The authors show that group A reflects the lowest cost and energy requirements, followed by B and C. On average, group A is the cheapest, group C requires most energy, and C recovers the largest quantity of P. The indicated units cannot reveal which technology is the most cost-effective, or if any of them is economically feasible. Sewage sludge ash processes (Egle et al., 2016), similar to group B in Mayer et al. (2016), are the most cost-effective options to recover P, although being more expensive than aqueous phase processes, i.e. group A, and less expensive than sewage sludge

processes. However, according to the authors the cost-effectiveness of most sewage sludge ash processes is still only close to the market price of raw phosphate rock.

Struvite recovery and reuse from digested sludge
While struvite precipitation is identified as a relatively ineffective technology through which only around 20% of the total P entering some WWTP can be retrieved, it is simultaneously a relatively cheap technique in comparison to alternative P recovery approaches (Geerts et al., 2014). Geerts et al. identify lower investment costs, a higher market price for P, or higher PO_4 concentrations as factors of increasing the economic feasibility of struvite recovery approaches. In comparison to struvite recovery from digested sludge, that from sludge waters has a low profitability.

Anaerobic digestion
Anaerobic digestion is another central element of the system alternatives in the BONUS RETURN case study areas. It describes the process which can lead to producing, for example, biogas. Bolzonella et al. (2018) reported on the performance of nutrient recovery approaches from anaerobic digestate of livestock manure. Performance differs depending upon the treatment system. Membrane systems can recover water of good quality while reducing the digestate volume, meanwhile drying systems can only treat some share of the digestate with effectiveness. Vantaanjoki (the BONUS RETURN case in Finland) is using horse manure, while Bolzonella et al. (2018) used pig, cow and chicken manure, energy crops, slaughterhouse residues and food waste.

Biogas and fertiliser production from manure
The economic efficiency of biogas and fertiliser production from manure has been studied by drawing on anaerobic digestion based on the physical in- and outputs (Yazan et al., 2018). Regional cooperation of manure suppliers and biogas producers can be economically beneficial depending on manure quantity, the transport distance, the dry content of the manure and the manure price or the manure discharge price.

3.4   Policy instruments and governance structures

3.4.1   *Review of EU and BSR directives and regulations*

In D 2.5 (Barquet et al., 2019), a review of the EU and BSR directives and regulations relating to the topic of nutrient reuse was carried out. These are summarized in Table 3. Most of the relevant EU legislation is related to managing nitrogen in farm systems and nitrogen and phosphorus in wastewater systems from cities as well as large pig and poultry farms. Reused phosphorus products are best fed into fertilizer production systems as feedstock since they are not promoted by present EU regulations as stand-alone sources.

As reviewed by Hukari et al. (2016) phosphorus recycling within the EU is governed by fragmented decision-making in regional administrations. Active regulatory support, such as recycling obligation or subsidies, is lacking. Legislation harmonisation, inclusion of recycled phosphorus in existing fertiliser regulations and support of new operators would speed up market penetration of novel technologies, reduce phosphorus losses and safeguard European quality standards.

HELCOM has initiated through the Baltic Sea Action Plan several policy instruments in order to improve the state of the Baltic Sea (BMEPC, 2018). HELCOM is a regional coordination instrument that relies on national regulations for implementation. The Baltic Sea Action Plan has been striving to

manage both nitrogen and phosphorus flows within the entire basin area by setting maximum allowable emission targets for each country. Both nitrogen and phosphorus inputs to the Baltic Sea have been decreasing since the 1980s. The total nitrogen input was about 7% larger than the maximum allowable input in 2015, whereas phosphorus input remained 44% above this threshold value (HELCOM, 2018). When it comes to removal of phosphorus and nitrogen in wastewater treatment, and recycling of phosphorus from sewage sludge, HELCOM has made recommendations that the contracting parties have agreed to (HELCOM, 2017a). Evidence of any monitoring of these recommendations or follow-up is, however, limited.

Table 3. EU Directives Affecting Nitrogen and Phosphorus Management in the Baltic Sea Region

Item	Main sector regulated	Relevance to reduction and reuse of land-based nutrients
Fertilizer Regulations Circular Economy package http://europa.eu/rapid/press-release_IP-18-6161_en.htm	Agriculture, municipal wastewater	Today only 5% of bio-waste is recycled. Currently, the EU imports around 6 Mtons of phosphate per year but could replace up to 30% of this by extraction from sewage sludge, biodegradable waste, meat and bone meal or manure.
Nitrates Directive 1991/676	Agriculture	Regulates amount of manure and fertilizer N that can be put on farmland (170 kg N/ha/yr); includes nitrate vulnerable zones (NVZs); manure phosphate is indirectly managed due to co-occurrence but can result in P overloading
Common Agricultural Policy https://circabc.europa.eu/sd/a/a2be04f2-fb29-4545-9355-85e9f8738170/4c%20-%20FaST.pptx	Agriculture	FAST, an app for farmers - Farm Sustainability Tools for Nutrients. Manure calculator based on nitrogen. Phosphorus excluded.
Groundwater Directive 2006/118	Agriculture, forestry, industry	Nitrate is the main focus; phosphate has been added since 2014
Waste Framework Directive 2008/98/EC	Solid waste	Includes recovery and recycling targets of waste products to reduce hazardous emissions; target for 2020 is 50% of municipal waste
Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)	Chemical industry; reuse products	Regulation of chemicals to protect human health and the environment. Linked to European Chemical Agency (ECHA) in Helsinki. Regulation of reuse products eg struvite.
Industrial Emissions Directive (IED 2010/75/EU)	Industry	BAT practices. Co-ordinated by IPPC bureau in Seville.
Industrial Pollution Prevention and Control Directive (IPPC 2017) BATs	Large pig and poultry farms	Provides limits for N and P emissions as well as best practices for manure management. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC107189/jrc107189_01_irpp_bref_07_2017.pdf
National Emissions Ceilings Directive	Agriculture and industry	Regulates air quality standards. Relevant to emissions of NO_x and NH_3

Water Framework Directive 2000/2000 Quality Objectives 2015/2021/2027	All human interventions; municipalities agriculture forestry, industry	Involves river basin management plans (RBMPs) aimed at maintaining good water quality. Strives to reduce nutrient losses in order to maintain water quality.
Sewage Sludge Directive (86/278/EEC)	Municipal wastewater treatment	Promotes use of treated sewage sludge in agriculture;
Urban Wastewater Treatment Directive	Municipal wastewater treatment	Promotes the treatment of wastewater and thus the production of sewage sludge
Landfill Directive	Municipal governments	Restricts the disposal of sludge in landfills prompting alternative solutions like composting and incineration prior to reuse as fertilizer amendment

3.4.2 *Analysis of policy and governance barriers and opportunities for innovations*

In addition, D 2.5 adapted a framework (Table 4) to review the policy and governance barriers and opportunities for innovations. The framework included eight analytical dimensions: structure, coordination, interactions and networks, capabilities, directionality, demand articulation, values, reflexivity and values. Data were collected from the literature and conducted interviews following the eight-dimensional analytical matrix. A set of themes within each analytical dimension was set up identifying different barriers and opportunities.

Table 4. Analytical framework in the context of technological innovation and transition (adapted from Weber and Rohracher (2012)).

Structure	The institutional infrastructure (e.g. regulations, legislation, standards) necessary to affect innovation activities.
Coordination	The organization between several components of a system that enables these to work effectively together across geographic scales, regime levels, and organizational hierarchies.
Interactions and networks	Interactions between actors with different roles and positions. The interactions include the exchange of knowledge, ideas, information and other resources.
Capabilities	Competencies, knowledge and resources that enable actors in a system and built capacity to adapt to new and changing circumstances and(technological) opportunities.
Directionality	A system's capacity to guide the direction of change, including formulating a shared long-term vision and signalling and communicating this vision.
Articulation	A system's capacity to anticipate users' needs, integrate, and act upon these.
Reflexivity	The capacity to monitor, learn and act upon knowledge, creating spaces for experimentation and learning and allowing a diversity of options for dealing with uncertainty
Values	Norms, attitudes, world views, awareness and the cultural and psychological dimensions of a technology, which can influence (innovation-related) policies, the demand and uptake of technologies

STRUCTURE
- Many reuse products are classified as waste and lack end-of-waste criteria
- Administrative and legal hurdles related to EU fertilizer regulation
- Administrative hurdles related to REACH
- Some reuse products are not allowed in organic farming
- Some alternative systems such as source separation require entirely new infrastructures
- There is a lack of subsidies, and hence incentives, for P-reuse

- Revision of the EU fertilizer regulation can improve market prospects for P-reuse products
- Novel P-reuse technologies have an advantage where agricultural reuse of sewage sludge is prohibited

CAPABILITIES
- Limited knowledge of the potential of several novel technologies for reuse
- Farmers seeking cross-sectoral collaboration and working in systemic issues are experiencing difficulties to access funding
- Limited local capacity for implementing reuse solutions

COORDINATION
- Silo-thinking and unclear division of responsibilities at different scales
- Lack of harmonized policies within the EU
- Goal conflicts in agricultural policies and subsidies
- Complex reuse policy landscape with heterogenous actors and multiple legal requirements

DIRECTIONALITY
- Lack of clarity and direction in current legislation, which hampers development and adoption of innovations for phosphorous reuse
- 'Circular economy' concept is gaining attention at EU level but remains to be translated and implemented at national level
- Low political support for nutrient recycling, with the exception of phosphorus
- There has historically been a low global awareness of the phosphorous issue, although this is gradually changing
- Current legislation on phosphorus is mainly designed to deal with eutrophication, not reuse
- Risk of new phosphorus policies steering in the wrong direction

- Increased policy attention towards phosphorous reuse

INTERACTIONS
- Reluctance to use recycled products from waste

REFLEXIVITY
- Wastewater sector is conservative and hard to change
- In national agricultural policy, there is often a narrow-minded focus on a single technology
- A narrow focus on incineration may close promising alternatives down
- Experience of limited public investment in alternative solutions in Sweden

ARTICULATION
- Products from waste water treatment plants do often not meet needs of farmers and fertilizer industry
- Need for better evidence to increase farmer acceptance, and to allow farmers to choose technology

POLICY AND GOVERNANCE

VALUES
- Entrenched linear ways of thinking and lack of awareness of circular economy in society
- Fear of consumer attitudes towards sludge, but lack of actual data
- Scepticism around the safety of water reuse practices in Europe
- Psychological barrier against productive use of human excreta
- Centralization paradigm dominates
- Focus on technological fixes rather than systemic change

Fig. 9. A brief summary of the findings across the eight analytical dimensions.

Results from this study (Fig. 9) highlight how the circular economy concept and a need to reuse P (including other nutrients, carbon, etc.) are gaining traction at the EU level with the Circular Economy Package (European Parliament, 2018) but remain to be mainstreamed at lower governance levels and among the broader public. Some Baltic Sea countries (such as Germany) are taking the lead in transitioning towards a more circular P economy and several other countries (such as Sweden) are reviewing their policies and may be moving in a similar direction. However, the report raises concerns about the formulation of such policies. For example, while the sludge reuse ban in Germany and requirements on P recovery do indeed provide a clear direction for technology developers, in practice it may give preference to one single type of technology, which risks crowding out other promising options and may lead to a lock-in into a sub-optimal system.

It was observed that policy steering towards P reuse at local, national and regional levels of governance is lacking. The legal framework for reused P products, particularly at the EU level remains to be both fragmented and complex. Sustainable solutions that ensure circularity could be more actively implemented when municipalities buy products and services from entrepreneurs. In addition, promotion of new business models with increased collaboration between wastewater treatment plants (a source of reusable P), fertilizer companies (a potential client for reusable P), and farmers (potential end-users of recycled P) are needed to achieve circular P economy.

3.5 Discussion: Sharpening of today's nutrient management policies to promote reuse of C, N and P

BONUS RETURN has reviewed in detail the global literature and found some 819 relevant studies describing technologies and practices that deal with reuse of nutrients and carbon (C) within the agriculture and wastewater sectors. Fertilizer use is the main source of input of nitrogen (N) and phosphorus (P) into the agriculture and wastewater sectors. The efficiency of use of these fertilizers from mining/production to final emission/disposal is rather low running at about 20-25% for phosphorus (Schröder et al. 2010). Because of the relatively low cost of mining/extraction/production, reuse products are often uneconomic and cannot compete. Wastewater treatment makes demands on effluent quality so phosphorus, biochemical oxygen demand (BOD) and nitrogen are removed into various potential reuse products. Within agriculture, manure, a source of C, N and P is a common product for reuse. For ecotechnologies to develop surrounding these potential flows requires regulations and policies providing incentives. Linking the N and P cycles with the more established policy spheres of climate change protection and adaptation that are focussed solely on the carbon cycle could help sharpen this development.

Phosphorus and nitrate behave very differently in the environment. Phosphate tends to bind to soil particles and organic compounds while nitrate particularly in groundwater and runoff is more mobile. As a result, the two nutrients cannot be managed in the same way. The Nitrates Directive manages nitrate reuse in manure by stipulating a maximum level of nitrate (170 kg N) that can be spread per ha. This has put all focus on nitrogen reuse in agricultural systems and phosphate loading has not been managed (Paterson et al., 2006). Similarly, when it comes to wastewater treatment, phosphate has received most attention. Preferential removal of P in wastewater treatment plants has cleaned up freshwater rivers and lakes (where P limits algal production) but has allowed the neglected nitrate to become a major source of eutrophication in marine coastal areas (where N limits algal production). This beckons for policies and regulations that take into account these major differences so that N and P can be managed in harmony.

Animal manure is applied to cropland to reduce the use of chemical fertilizer - but it needs to be managed on the basis of its phosphorus and its nitrogen content simultaneously. As stated above, the single largest significant practice of nutrient reuse is that of spreading animal manure onto farmland. However, spreading of animal manure on fields based alone on nitrogen crop require-ments has caused serious overloading of phosphorus in farm soil and watersheds. Most manures contain N and P in a ratio of about 1-2 to 1 while most crops require 5-6 to 1 (Paterson et al., 2006). In order to meet the nitrogen requirements, farmers end up applying up to 10 times the required amount of P onto soils. This results in significant overloading, soil enrichment and eventual loss of P through seasonal runoff. EU legislation does not attempt to control this problem (Barreau et al., 2018; Van Grinsven et al., 2016) since the practices are governed mainly by the Nitrates Directive. Some of the countries around the Baltic Sea have created national regulations to deal with this problem, for instance Sweden, Germany and Denmark's "harmony rules"[3] (HELCOM, 2017b) but like most EU countries, the Water Framework Directive is used to identify phosphorus sensitive areas and this does not manage the question of manure spreading on croplands.

Another key factor determining potential development of reuse products is the cost and availability of cheap fertilizer which determines the overall marketability and competitiveness of the reuse product. The need to increase sovereign sources of phosphorus is a driver that promotes reuse of P.

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[3] The Danish "harmony rules" outline requirements for the minimum size of the area a livestock holding must have available for spreading livestock manure from the respective livestock production

That commercial P-rock reserves are concentrated to only a few countries (USGS, 2019) with Morocco currently possessing >70% of the global reserves, creates a geopolitical arena whereby global availability could become jeopardized much like what happened during the oil crisis of the early 1970s. Currently, EU imports 90% of its P and there is but one mine in Finland that presently serves only the Nordic areas of Europe. This is why the EU has put P-rock and white P on the list of critical raw materials (DG Enterprise, 2017).

A significant driver that affects the reuse of organic material in both agriculture and wastewater is the need to close the loop on carbon in order to reduce greenhouse gas emissions. This is the case for production of renewable energy in the form of biogas from organic sources such as sludge, manure and farm and food wastes. The resulting sludge is a source of phosphorus that can be extracted following incineration, or the sludge can be applied to productive farmland. Somewhat connected to this is the legislation that has banned ocean dumping and landfills for the disposal of sludge and manure. This has promoted the use of sludge and manure in these reuse systems.

Although the above should be producing significant changes in how waste is managed, the EU directives and Baltic Sea HELCOM recommendations do not clearly promote or provide incentives for circular nutrient systems. These directives and recommendations suffer from decades of traditional linear systems management where resources once used are designed to produce waste for disposal.

Disincentives to reprocess agriculture and urban organic wastes are steered somewhat by attitudes within society. There are negative attitudes among farmers, health officials and policy makers about spreading sewage sludge on fields because of unwanted contaminants e.g. pharmaceuticals, heavy metals and microplastics. This should be a driver for cleaning up these systems in order to reduce or eliminate these substances so the nutrient loop can be closed.

Also, the risks surrounding exposure to natural cadmium by production of fertilizer from phosphate rock are also relevant to this discussion. Sedimentary P-rock contains natural cadmium at levels (Ulrich, 2019) that the EU is presently attempting to regulate in order to reduce the accumulation of cadmium in our soil, food and our bodies. Studies in Sweden indicate that cadmium-related bone fractures are already a significant problem costing the Swedish government annually ca >4 billion SEK in health care costs (KEMI, 2012). Phosphorus recycling within agriculture and wastewater provides an added opportunity to produce safe, low cadmium feedstocks.

Overall the need for reuse of nutrients and carbon in the BSR is well justified and this report shows there is progress in the making. With increased understanding and interest within society, among policymakers, farmers and industry, further achievements will be seen.

3.6   Conclusions

The BONUS RETURN project carried out a review and synthesis of ecotechnologies and practices for carbon and nutrient recovery and reuse from wastewater and agriculture systems based on a systematic mapping of the academic and grey literature - some 820 different approaches were mapped.

Relating to agriculture, ecotechnologies and practices are centred around reuse of manure on cropland. Technologies that are used to refine or mineralize manure include aerobic digestion and struvite production. The other important source of nutrients and organic material from farms is plant

material or crop residues. When combined with manure to increase carbon content the most common technologies promoting mineralization are composting, vermicomposting, pyrolysis/biochar production and anaerobic digestion/co-digestion. Recovery of nitrogen was slightly more common than phosphorus recovery. These were significantly more common than carbon recovery.

For wastewater, energy recovery (e.g. biogas) dominates recycling practices. Nutrients and carbon are recovered in sludge residues following BOD reduction and P precipitation from the wastewater. P and N can also be extracted using magnesium in the production of struvite. Recovery of phosphorus is more common than nitrogen. Incineration of sludge can provide ash material that can be a source of P for further extraction.

For nutrient and carbon reuse products from agriculture and municipal wastewater to be commercial, they need to match the market prices for extracting the equivalent materials from rock phosphate, natural gas (for ammonia and biogas production) and energy systems (for energy-based carbon and heat reuse). In most cases there are additional factors that come into play that act as drivers to promote nutrient and carbon recycling. These include the need to secure sovereign sources of phosphorus, the need to reduce greenhouse gas emissions, and the need to find alternatives to ocean dumping and landfills for the disposal of excess sludge and manure that are too expensive to transport.

With respect to policy instruments and governance structures the European Parliament has recently approved the Circular Economy Package which in effect provides reforms to some of the Directives already in place. In theory, this can mean a facilitation towards recycling of nutrients and carbon within the agriculture and wastewater sectors. Phosphorus, however, has yet to be included in the EU Nitrates Directive in order to better harmonize the reuse of P with N in agriculture systems.

HELCOM works under the umbrella of the EU as a regional coordination body. Its recommendations on nutrient emissions and reuse are meant to be implemented by member countries. Major decreases in fertiliser use have occurred in the Baltic Sea Region and nutrient loading from wastewater sources has also decreased over recent decades. Promotion of nutrient and carbon reuse products will further reduce the inflows to the Baltic Sea basin.

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