BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits
https://www.bonusprojects.org/bonusprojects/the_projects/blue_baltic_projects/return
www.bonusreturn.eu

Deliverable No: D.2.5 – Report on current policy instruments and governance structures in BSR
Ref: WP 2 Task 2.3.
Lead participant: SEI
Date: 4 Jan 2019

BONUS RETURN has received funding from BONUS (Art 185), funded jointly by the EU and Swedish Foundation for Strategic Environmental Research FORMAS, Sweden's innovation agency VINNOVA, Academy of Finland and National Centre for Research and Development in Poland.

Deliverable Title	**D.2.5 – Report on current policy instruments and governance structures in BSR**
Filename	BONUSRETURN_D.2.5_ Report on current policy instruments and governance structures in BSR
Authors	Karina, Barquet (SEI); Linn, Järnberg (SEI); Biljana, Macura (SEI);
Contributors	Arno, Rosemarin (SEI), Filippa Ek
Date	04/01/2019

Start of the project: 01/05/2017
End of the project: 01/05/2020
Project coordinator: Stockholm Environment Institute (SEI)

Dissemination level

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.

Table of Contents

EXECUTIVE SUMMARY

This study sheds light on the major policy and governance barriers and opportunities affecting the development, choice and implementation of innovations for phosphorus (P) reuse, including technologies and practices in the agriculture and wastewater treatment sectors. We adapt a 'systems failures' framework that merges an innovation systems perspective with elements from the multi-level perspective of the socio-technical transitions literature. The framework allows for in depth analysis of policy and governance barriers and opportunities for innovations. The framework includes eight analytical dimensions: structure, coordination, interactions and networks, capabilities, directionality, demand articulation, values, reflexivity and values. To collect data on different barriers and opportunities for technological innovations in the field of P reuse, we have searched for literature on Web of Science Core Collections and Google Scholar. We have applied predefined eligibility criteria and screened literature at three stages: title, abstract and full text. We have also conducted 10 key-informant interviews to corroborate literature review findings. We have extracted relevant data in the form of quotes and summaries into the eight-dimensional analytical matrix. We have thereafter created a set of themes within each analytical dimension, identifying different barriers and opportunities.

Results from this study highlight how the circular economy concept and a need to reuse P (including other nutrients, carbon, etc.) is gaining traction at the EU level with the Circular Economy package but remains 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 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.

Based on the findings of this report (and taking into account identified limitations of our approach), we argue that there is a need to increase policy steering towards P reuse, without closing promising systemic solutions. Mainstreaming the idea of circular economy across society and local, national and supranational governance structures is a priority. Continuing efforts to simplify the legal framework for reused P products, particularly at EU level is necessary. Sustainable solutions that ensure circularity could be more actively implemented when municipalities buy products and services from entrepreneurs. Testbeds for innovations in municipalities should favour circular solutions with multiple benefits to society and minimized effects upon the environment. Municipalities can create clearer guidelines and requirements that send strong signals to entrepreneurs on the type of technologies desired for the development of the city, while at the same time making it easier for circular innovations to succeed. In addition, promotion of new business models with increased collaboration between waste water treatment plants (i.e. a source of reused P), fertilizer companies (i.e. a potential client for reused P), and farmers (i.e. potential end-users of recycled P) is needed to achieve circular P economy.

1 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.

1.1 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.

1.2 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.

1.1 DELIVERABLE CONTEXT AND OBJECTIVE

The current deliverable (Del.No. 2.5) is part of WP 2. The objectives of WP 2 are to summarize the evidence pertaining to reuse of carbon and nutrients using ecotechnologies.

This deliverable summarizes major policy and governance barriers and opportunities affecting the development, choice and implementation of innovations for phosphorus (P) reuse (technologies and practices) in the agriculture and wastewater treatment sectors

1.2 OUTLINE OF THE REPORT

This report is structured around 5 subsections as follows:
2.1 Objectives
2.2 Background
2.3 Theoretical framework
2.4 Methodology
2.5 Results

2 REPORT ON CURRENT POLICY INSTRUMENTS AND GOVERNANCE STRUCTURES IN BSR

2.1 OBJECTIVES

If nutrients are a resource in land, why are they still in our oceans? Why are not more cities taking up technologies and practices for reuse? Why are sectors not taking up innovations developed? These are some of questions that lie behind this study. Throughout the course of BONUS RETURN, stakeholders have flagged up three crucial and interconnected aspects for addressing these questions: policy and governance, markets, and technology/practice development. This study focuses on policy and governance (the other two aspects are currently being assessed in the project). The main question this review addresses is:

What policy and governance opportunities, drivers and barriers affect phosphorus reuse in agricultural and wastewater sectors in the Baltic Sea region?

This study focuses exclusively on P reuse for two reasons. First, while nitrogen (N), Carbon (C), P and other nutrients are essential to the life of plants and animals, and they are not substitutable, the potential of finding supplies of N and C for agriculture is effectively unlimited, while mineable P reserves are relatively very limited. This has implications for the value of recovery and reuse of P versus other nutrients and C. For instance, whereas recovering N and C from wastewater and some agriculture practices would be desirable to limit emissions (of C and N lost to the environment through water run-off from fields, animal waste and gas emissions from soil microbe metabolism) (Hénault et al., 2012; Oertel et al., 2016) the recovery value is mainly environmental (i.e., for the purpose of limiting emissions and pollution) and has a limited market value for reuse (apart from their reuse through application of manure and compost in farming). By contrast, the resource limitations surrounding P present clear financial and political incentives for P recovery and reuse. Because of this, some industries and wastewater facilities already place a high value on recycled phosphate, especially for applications in agriculture.

The paper is divided into the following sections: background, theoretical framework, methodology, results, discussion and conclusions, including recommendations for policy and future research.

2.2 BACKGROUND

In the literature, two aspects are often highlighted for understanding the importance of P: the geopolitical challenges at production and consumption, and its environmental dimension. Below we summarize the main arguments of each.

2.2.1 A geopolitical challenge

P is essential for crop growth and food production, and most of the P applied to agricultural land comes from phosphate rock (PR), a non-renewable resource. The distribution of PR reserves and the share of current production are primarily concentrated in Morocco (which includes Western Sahara) and China.[1] Global PR reserves depend on how phosphate mining industries are operated at different reserve-production (R/P) ratios, which determines the lifetime of PR reserves nationally and, in turn, the global distribution of both P reserves and production in the future (Cooper et al., 2011). Cooper et al. (2011) calculated how the global distribution of PR reserves and production would change between 2011 and 2100. Their results show that 70% of global production is currently produced from reserves which will be depleted within 100 years and combining this with increasing demand (due to increased food production) will result in a significant global production deficit, which by 2070 will be larger than current production. They conclude that unless additional sources of P can be accessed, or society can significantly increase P recycling, future global P security will be increasingly reliant on a single country, i.e. Morocco (Cooper et al., 2011).

World demand for P keeps growing (Neset and Cordell, 2012). For countries lacking P deposits this implies complete dependency on P imports to produce food, which in turn translates into vulnerability to market fluctuations in fertilizer and mineral P prices (Carolus, 2018) as well as vulnerability to market protectionism (Neset and Cordell, 2012). Trends and developments on the global phosphate rock market are putting the EU's security of supply of phosphate rock under increasing pressure, as demand (associated with food production and phosphate fertilizer) is rising (Derricott, 2018). The EU is almost entirely dependent on imports of phosphate rock, primarily from Russia and countries in the Middle East and North Africa (MENA), with a mine in Finland (Siilinjärvi) being the only operational source within the EU (Dawson and Hilton, 2011). The risk of supply disruptions in the EU is regarded as high because these key P exporter countries are suffering from geopolitical turmoil. For example, the Arab Spring had a heavy impact on global phosphate rock production and thereafter on P prices; while Syria has virtually stopped its exports to Europe because of ongoing conflict. Consequently, a stable supply to the EU from the MENA region cannot be guaranteed and phosphate prices are expected to remain high in the coming years (de Rider et al., 2012)

To complicate things further, the sedimentary P-rock in Morocco and elsewhere in the world is contaminated by naturally occurring cadmium (50 to 200 mg Cd/kg P_2O_5) (Smolders and Six, 2013). High cadmium exposure is known to cause bone fractures (Engström et al., 2011) and other physiological impacts, therefore, enrichment of agricultural soils and food crops with cadmium is a growing concern in the EU. De Rider et al. (2012) highlight how industry statistics indicate that global production of igneous low-cadmium phosphate is roughly equal to the EU's consumption. At the same time, the EU's share in the global low-cadmium phosphate market (despite significant low-cadmium rock imports from Russia) is extremely low (around 10%). Hence, the EU needs to consider not just how to secure its supply of phosphate, but also its supply of low-cadmium phosphate.

2.2.2 Environmental dimension

Issues surrounding P availability and affordability, and food security at large, are also intimately linked to the same factors that contribute to climate change. A significant amount of fossil-fuel energy is required to extract, transport, and process phosphate rock across the world to create the P

[1] Other major holders of phosphate rock reserves (from large to small) are Finland, Algeria, Syria, Jordan, South Africa, the US and Russia.

fertilizers required to feed the planet. The main energy requirement for producing P fertilisers comes from the burning of sulphur (and oil refining) to make sulphuric acid, which is the acid used to dissolve phosphate rock in the 'wet' process for manufacturing phosphoric acid. Historically, sulphur production has experienced extreme price volatility (linked to oil prices), making strategic production planning and long-term investment in production capacity challenging (Dawson and Hilton, 2011).

Despite its irreplaceability, the use of phosphate remains inefficient in many respects. In agriculture, a proxy measure for the loss of phosphate is 'phosphorus balance': the amount of phosphate applied to the land minus the amount harvested in the form of useful crops. This tells whether agriculture is operating at a phosphate deficit or surplus. A larger surplus implies greater loss and waste of phosphate. A glance at the phosphate balance shows that all but three EU countries experience phosphate surpluses, indicating that more can be done to ensure that the phosphate applied to land is used in the most efficient way (de Rider et al., 2012).

Outside of agriculture, phosphate is often wasted in different ways. For instance, urban waste water contains significant amounts of phosphate. In the EU, urban waste water contains about 1.14 megatons P_2O_5 per year which for example equalled to a share of 34% of the EU imported phosphate in 2011 (3.4 megatons P_2O_5 in total) (de Rider et al., 2012). However, over the period 2005–2007 on average only slightly more than 40% of sewage sludge within the EU was reused in agriculture, or approximately 0.12 megatons of P (154), whilst the remaining 60% was wasted (Rosemarin et al., 2011; Ross and Omelon, 2018).

Nutrient runoff is a primary cause of eutrophication, leading sometimes to harmful algal blooms (HABs) and oxygen-free sea bottoms. Increased phosphate concentrations in water and resulting eutrophication are also associated with higher costs and difficulties in drinking water purification (Melia et al., 2017) and health risks. Some cyanobacteria produce toxins, which can cause serious and occasionally fatal human liver, digestive, neurological, and skin diseases (Paerl and Huisman, 2008).

While the interactive effects of future eutrophication and climate change on harmful cyanobacterial blooms are complex, much of the current knowledge suggests that climate change is a catalyst for the further expansion of these temperature-sensitive blooms by enhancing the magnitude and frequency of algae blooming (O'Neil et al., 2012; Paerl and Huisman, 2008; Visser et al., 2016). In the North Atlantic and North Pacific Oceans, evidence suggests that increasing ocean temperatures have already facilitated the intensification of HABs and thus contribute to an expanding human health threat (Gobler et al., 2017). Cyanobacterial blooms may even locally increase water temperatures through the intense absorption of light (Paerl and Paul, 2012), or by competing out other algal phytoplankton species which play a key role in several global biogeochemical cycles and thereby exert important feedback effects on climate by influencing the partitioning of climate-relevant gases between the ocean and the atmosphere (Guinder and Molinero, 2013). Global warming also affects patterns of precipitation and drought. These changes in the hydrological cycle could further enhance cyanobacterial dominance. For example, more intense precipitation will increase surface and groundwater nutrient discharge into water bodies (Paerl and Huisman, 2008).

In the summer of 2018, The Finnish Environment Institute (SYKE) published an algae forecast for marine areas in which it predicted that the majority of the Gulf of Finland down to Poland's shores in the Baltic Sea faced considerable risk of blue-green algae blooms (SYKE, 2018). The forecast turned out correct, but on an even broader scale than predicted. The wind-calm and hot weather period boosted the formation of blue-green algae rafts. This is linked to the global increased warming coupled with anthropogenic eutrophication, which has increased the volume of anoxic water mass (areas severely depleted of dissolved oxygen and a more severe form of hypoxia). In the Baltic Sea 18% of the bottom area is affected by anoxia and 28% by hypoxia, whilst oxygen concentrations in the deep water are still near zero (Hansson et al., 2018). This condition in the Baltic Sea is further exacerbated by the proliferation of algae blooms. In various areas this has led to the regular appearance of "dead zones" in the basin. According to researchers from Finland's University of Turku, the dead zone in 2018 is estimated to span about 70,000 square kilometres (27,000 square miles). While climate change is not the major cause for these dead zones, global warming is likely to exacerbate oxygen depletion and delay the recovery of the basin (Jokinen et al., 2018).

To address both eutrophication problems and challenges related to the extraction of virgin phosphate rock, a range of interventions are required along the P value chain to e.g. increase mining efficiency and to change agricultural practices related to fertilizer application.

Phosphate currently moves mainly in a linear direction from mines to distant locations for crop production, processing, and consumption (Haas et al. 2015). However, attention has increased towards the potential for moving towards a circular system to improve P use efficiency and waste recovery from human and animal excreta to food and crop wastes (Cordell et al., 2011; Schröder et al., 2011).

Boarding a discussion of a circular P system demands consideration of inputs and outputs from production to consumption and the processes in between. The value chain of P, and innovations addressing P production, spreads across geographies and involves a variety of actors from various private and public sectors. This study is focusing primarily on the context of a circular economy of P in the Baltic Sea Region and the policy and governance aspects that impact innovation development and uptake for P reuse. This includes policy and regulations within BONUS RETURN case study sites (Sweden, Poland and Finland), in the Baltic Sea Region, but also relevant EU-level directives and frameworks affecting the region.

There are different definitions of a circular economy, all of which emphasize maximizing the value of the resources in use (i.e., "stock optimization"), minimizing waste (i.e., eco-efficiency), and enabling materials to maintain their status as resources (i.e., eco-effectiveness) in a closed and circular system (Earth) with limited assimilative capacity (Kalmykova et al., 2018). This cycle is commonly captured through the "Rs strategy": Reduce, Reuse, Recycle and Recover. A circular economy demands circularity not only in how substances and materials flow, but also in the policy and governance processes, market mechanisms, and technologies that should enable these flows. This study focuses exclusively on the reuse of P, i.e. recovering lost P and turning it into a product that can be reused for production processes (various industries) and this way "close the loop". The study focuses specifically on closing the loop between wastewater treatment and agriculture, with a focus on assessing the barriers and opportunities for socio-technical innovations in prompting a circular economy of P.

2.3 THEORETICAL FRAMEWORK

Socio-technical transitions are complex, dynamic, political processes that involve changes at multiple levels (Rotmans et al., 2001). In transitions research, "transition" has been mainly employed to analyse changes in societal subsystems (e.g. energy, mobility, cities), focusing on social, technological and institutional interactions (Loorbach et al., 2017).

Social and technological innovation is fundamental in supporting transitions. At the same time, social processes shape the development and use of such innovations, but innovation in turn triggers new social practices. This creates new conditions for how society relates to social and technological innovations (Patterson et al., 2017). These conditions are likely to be deeply political and contested because of the losses and gains they will generate (Barquet, 2018).

Geels (2011) outlines three main characteristics that distinguish sustainability transitions from other types of socio-technical transition. First, sustainability transitions are goal-oriented rather than 'emergent' as many socio-technical transitions have been, since they are actively steered towards sustainable outcomes. Second, most 'sustainable' solutions are often characterized by being a collective good and thereby do not offer obvious user benefits, but also, they often score lower on price/performance dimensions compared to established technologies. This makes it unlikely that environmental innovations will be able to replace existing systems without changes in economic and policy structures (e.g., taxes, subsidies, regulatory frameworks). Third, the sectors where sustainability transitions are most needed are also those characterized by centralized systems (e.g. waste water) or large firms (e.g. fertilizer industry) that hold a strong position and comparative advantage to smaller-scale and upcoming innovations.

Socio-technical transitions theory is relevant for understanding how and why certain unsustainable development paths have evolved and what constrains a society or sector from shifting toward more sustainable technical practices and social, economic, and political institutions. However, the theory has several shortcomings. Lawhon and Murphy (2012) identify four aspects relevant to the present study. First, is the focus on technology as the means to achieve sustainability with little consideration of how technology is embedded in society, how technology is produced, owned, and for what ends is being used. Second, the literature tends to account for a specific subset of elite actors directly involved in the technical or economic changes (e.g. corporations, innovators, scientists) with little regards to individuals or groups affected by the technologies and the social and political changes associated with these. Third, space and scale are undertheorized and there is a tendency to favour the national scale as the point of analysis. The dynamics through which knowledge and socio-economic practices are embedded in a diversity of spacetime contexts are not properly analysed. As a result, the theory does not adequately explain the spatially-uneven progress towards sustainability. Fourth, as a result of the focus on technology and limiting the range of actors involved in the analysis, sociotechnical transition studies and transition management avoid the issue of power. Technology is not given agency, and actors are often treated as rational and apolitical. However, exploring the every-day politics inherent in decision-making processes is crucial for understanding why, where and how transitions occur (Lawhon and Murphy, 2012).

In this report we address some of the gaps named above by applying an analytical framework that helps to identify factors that are currently constraining or enabling a circular P system. The purpose of this framework is to improve our understanding of what (policy or governance) is failing or enabling the uptake and application of innovations for P reuse and where in the process is this taking place? We do this by assessing different dimensions influencing the system and breaking down policy or governance problems or opportunities named in the literature into better defined analytical categories that can help locate bottlenecks in the innovation-upscaling-implementation process and thereafter identify recommendations for action.

We adapt a 'systems failures' framework developed by Weber and Rohracher (2012). The framework allows for in depth analysis of barriers and opportunities for P reuse innovation related to policy and governance. The framework covers the following analytical dimensions: structure, coordination, interactions and networks, capabilities, directionality, demand articulation, values, reflexivity and values (see **Table 1** for definitions of the dimensions).

We use a conception of governance that encompasses institutional properties (polity or the system of rules that shapes the actions of social actors), actor constellations (politics and power relation between political actors) and policy instruments (steering instruments) (Treib et al., 2007).

Our version of the analytical framework differs to Weber and Rohracher's (2012) in the following aspects: (1) We use the concepts as neutral categories, rather than "failures" (see definitions in Table 1). (2) We use what they conceptualize as "structural" and "transformational" system failures and (3) we exclude their category of "market failures" because our focus was on barriers and opportunities in policy and governance. (4) We have merged "infrastructural failure" and "institutional failure" to form the "structure" category. (5) We have redefined the meaning of "reflexivity" to encompass aspects related to the use of knowledge (and acting upon it) for learning, and not only monitoring, anticipation and involvement of actors. (6) We reformulated what Weber and Rohracher (2012) named "informal institutions" (under "institutional failures") and added a separate category titled "values" to emphasise behavioural and cultural aspects that influence demand and uptake of technologies innovation policies.

Table 1 Analytical framework in the context of technological innovation and transition (adapted from Weber and Rohracher (2012)).

Analytical dimension	***Definition***
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

2.4 METHODOLOGY

We have used two data collection methods for this study: 1) literature review and 2) key-informant interviews.

Literature review

Literature review included a systematic approach to literature searching and eligibility screening as described below.

- *Searching for articles*

We searched for articles using Google Scholar and Web of Science Core Collections (WoSCC).

Search performed using Google Scholar (which is an effective tool for grey literature searches (Haddaway et al., 2015)) combined the following English language search terms: *policy; regulations; instruments; barriers; recycle; reuse; nutrients; phosphorus; carbon.* The search was conducted in September 2018 and it was restricted to articles published between 2008 and 2018. First 70 search results (sorted by relevance) were extracted as citations and introduced into a reference management software (Zotero).

Search performed on WoSCC (consisting of the following indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, and ESCI) was conducted during October 2018. Searches were performed using subscription of Stockholm University. The searches were conducted using English language search terms.

The following search string was used in WoSCC:

((reus OR "circular econom*" OR "nutrient econom*" OR recycl* OR "secondary phosh*" OR "recovery technolog*" OR reclamation OR reclaim*) AND (nutrient* OR phosphorus OR phosphate OR urine OR excret* OR feces OR fecal OR sludge OR struvite OR "phosphoric acid" OR manure OR faecal OR faeces OR slurry OR effluent OR wastewater OR runoff OR wetland* OR riparian OR ash* OR compost OR "slaughterhouse waste" OR fertilizer*) AND (institut* OR polic* OR govern* OR law* OR directive* OR bylaw* OR attitude* OR perception* OR "technological innovation*" OR acceptabil* OR legal* OR "value chain*" OR financ* OR investment* OR scaling OR adopt* OR upscaling OR "livestock licenses" OR "emission permit*" OR tax OR taxes OR "cadmium tax" OR "sustainable phosphorus" OR "socio-technical transition*"))*

The search combined 3 substrings, using search terms connected to (1) ecotechnology and reuse; (2) nutrients and (3) barriers and opportunities. The final search string is the result of numerous iterations performed in WoSCC to increase search precision and sensitivity. We have restricted our searches to the period of 2008-2018. This search yielded 6843 results, but due to time and resource constraints we have downloaded first 500 results (sorted by relevance).

All search results were introduced into a review management software where they were combined, and duplicated were removed (5 in total). Search results were then screened for eligibility screening.

- *Article screening and study eligibility criteria*

Screening of literature was conducted at three levels: at title, abstract and full text. The full texts of potentially relevant abstracts were retrieved, tracking those that could not be located or accessed. Retrieved records were screened at full text, with each record being assessed by one experienced reviewer. In case of doubt, we have included the paper to the next stage of screening.

Prior to commencing screening at full text, consistency checking was performed on a subset of articles (5%). 5 full text records were independently screened by all reviewers. The results of the consistency checking were compared between reviewers, all disagreements were discussed in detail and eligibility criteria were clarified were needed.

The following eligibility criteria were applied at all levels of screening:

1) Setting: We have included studies from and relevant to the Baltic Sea region which includes Russia, Denmark, Estonia, Latvia, Finland, Germany, Lithuania, Poland, and Sweden. There were several relevant studies that have not stated the geographical scope and they were also included.
2) Sector: We have included studies describing ecotechnologies (and innovation) in agricultural and waste water sector. We excluded ecotechnologies in e.g. forestry, textile and food processing industry.
3) Type of ecotechnology: We have included studies on ecotechnologies and practices for reuse of P (e.g. technologies for reuse of animal manure or struvite). Studies that focused on P reduction or recovery only were not included.
4) Outcome: We have included studies that described policy, markets or technological barriers and opportunities for P reuse. Studies that described a technology without mentioning any of the

above, were excluded. Cost-benefit analyses of abatement measures, studies without innovation focus and only on the benefits of reducing eutrophication were excluded.

Semi-structured key-informant interviews

The objective of semi-structured interviews was to corroborate and supplement findings of the literature review. During October 2018 we have interviewed ten experts including innovators in the private and public sector (4), scientists (4), an interest group (1) and a farmer representative (1). The interview guide included questions about: policy coherence, societal perceptions and user awareness of (new) eco-technologies, financing and markets for eco-technological innovations, paths and tools for promoting and developing technological innovations. The questions were adapted to each category of the interviewees. The interviews were conducted either face-to-face or over Skype, depending on the availability and location of the interviewee. They lasted between 60 and 90 minutes and were recorded and summarised by a researcher.

Data coding, extraction and synthesis

Data from studies from the literature review were extracted from the "Results" sections of included studies and consisted of study findings reported by authors and clearly supported by study. Data from interviews included excerpts, verbatim quotations or rich summaries from interview notes. All data were extracted directly to a spreadsheet and mapped on the eight analytical dimensions (see Analytical framework). Data were classified as either a barrier or an opportunity. Within each analytical dimension, data were then carefully summarised into themes (see Results).

2.5 RESULTS

We have screened 565 articles at title level, out of which 434 titles were included for abstract screening, and 131 titles were excluded. At the abstract level, we have included 142 articles for further retrieval and full text screening, while 292 abstracts were excluded. We successfully retrieved 125 articles that were then screened at full text. We have excluded 103 full texts based on ineligible geographical scope, target sector, ecotechnology, nutrient, study type or article language. Finally, we included and synthesised evidence from 22 eligible articles (8 identified through the search in WoSCC and 14 in Google Scholar) (see **Table 2**).

Table 2. A list of included studies with identified barriers and opportunities according to eight analytical dimensions.

	Short title	**Full reference**	**Barriers**	**Opportunities**
1	Bolzonella et al. 2018	Bolzonella D, Fatone F, Gottardo M, Frison N, 2018. Nutrients recovery from anaerobic digestate of agro-waste: Techno-economic assessment of full scale applications. Journal Of Environmental Management 216, 111–119. https://doi.org/10.1016/j.jenvman.2017.08.026	Structure	

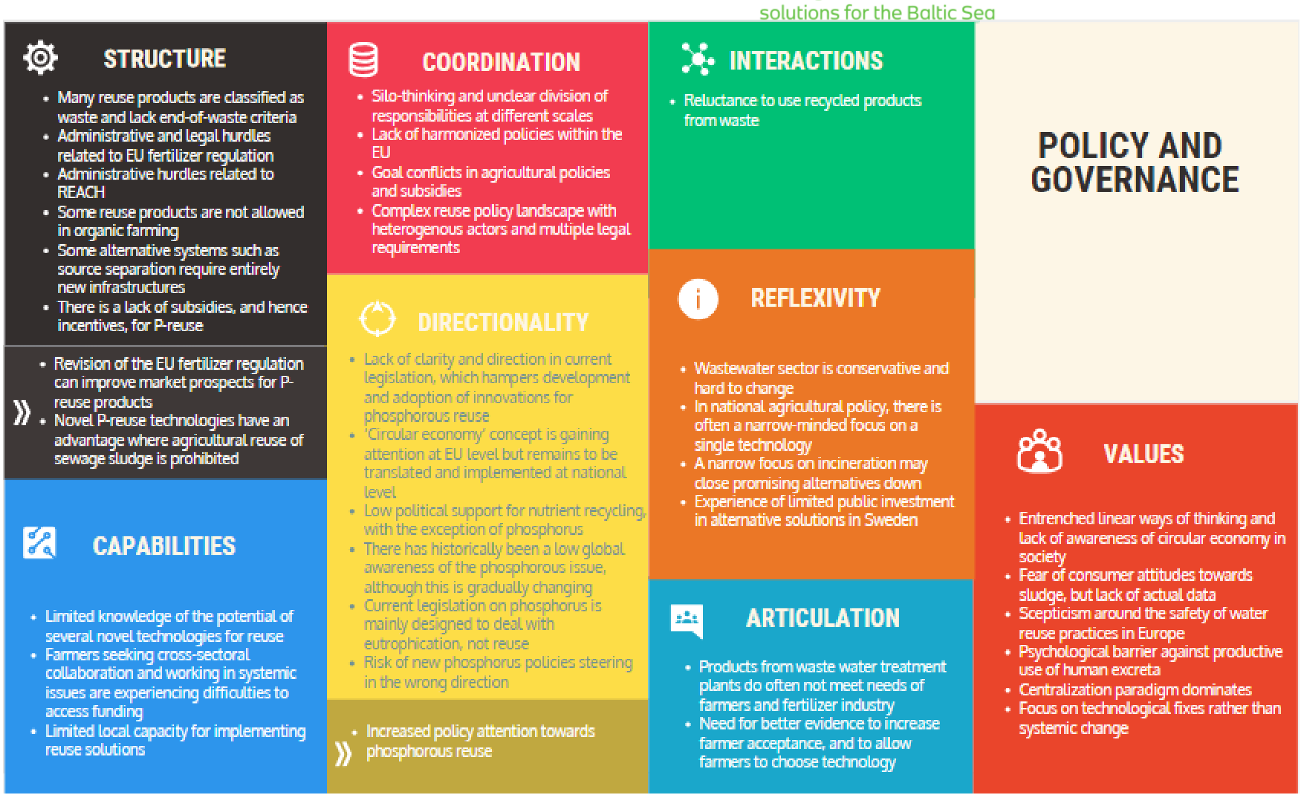
2	Cordell et al. 2009	Cordell, D., Drangert, J.-O., White, S., 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change 19, 292–305. https://doi.org/10.1016/j.gloenvcha.2008.10.009	Coordination, Directionality, Values	
3	Cordell et al. 2011	Cordell, D., Rosemarin, A., Schröder, J.J., Smit, A.L., 2011. Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. Chemosphere 84, 747–758. https://doi.org/10.1016/j.chemosphere.2011.02.032	Values	
4	Dawson and Hilton 2011	Dawson, C.J., Hilton, J., 2011. Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. Food Policy 36, S14–S22. https://doi.org/10.1016/j.foodpol.2010.11.012	Directionality	
5	de Boer MA et al. 2018	de Boer MA, Romeo-Hall AG, Rooimans TM, Slootweg JC, 2018. An Assessment of the Drivers and Barriers for the Deployment of Urban Phosphorus Recovery Technologies: A Case Study of The Netherlands. SUSTAINABILITY 10. https://doi.org/10.3390/su10061790	Structure, Coordination	
6	de Rider et al. 2012	de Rider, M., de Jong, S., Polchar, J., Lingemann, S., 2012. Risks and Opportunities in the Global Phosphate Rock Market.	Interactions and networks	
7	Egle et al. 2015	Egle, L., Rechberger H, Zessner M, 2015. Overview and description of technologies for recovering phosphorus from municipal wastewater. Resources Conservation And Recycling 105, 325–346. https://doi.org/10.1016/j.resconrec.2015.09.016	Structure	
8	Egle et al. 2016	Egle, L., Rechberger, H., Krampe, J., Zessner, M., 2016. Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies. Science of The Total Environment 571, 522–542. https://doi.org/10.1016/j.scitotenv.2016.07.019		Structure
9	Ehlert & Schoumans 2015	Ehlert, P.A.I., Schoumans, O.F., 2015. Products, by-products and recovered secondary materials from processed animal manure. Wageningen Alterra 30.	Structure, Coordination	

10	Fam & Mitchel 2013	Fam, D.M., Mitchell, C.A., 2013. Sustainable innovation in wastewater management: lessons for nutrient recovery and reuse. Local Environment 18, 769–780. https://doi.org/10.1080/13549839.2012.716408 v	Structure, Reflexivity, Values	
11	Fam et al. 2010	Fam, D., Mitchell, C., Abeysuria, K., 2010. Institutional Challenges to System Innovation in Wastewater Management – The Case of Urine Diversion in Sweden. Proceedings of the Water Environment Federation 2010, 871–888. https://doi.org/10.2175/193864710798284706	Structure	Structure, Directionality
12	Hukari et al. 2016	Hukari, S., Hermann, L., Nättorp, A., 2016. From wastewater to fertilisers — Technical overview and critical review of European legislation governing phosphorus recycling. Science of The Total Environment 542, 1127–1135. https://doi.org/10.1016/j.scitotenv.2015.09.064	Structure, Coordination	
13	Maass & Grundmann 2018	Maass O, Grundmann P, 2018. Governing Transactions and Interdependences between Linked Value Chains in a Circular Economy: The Case of Wastewater Reuse in Braunschweig (Germany). Sustainability 10. https://doi.org/10.3390/su10041125	Structure, Coordination, Values	Reflexivity
14	McConville et al. 2017a	McConville, J.R., Kvarnström, E., Jönsson, H., Kärrman, E., Johansson, M., 2017. Is the Swedish wastewater sector ready for a transition to source separation? Desalination And Water Treatment 91, 320–328. https://doi.org/10.5004/dwt.2017.20881	Structure	
15	McConville et al. 2017b	McConville JR, Kvarnstrom E, Jonsson H, Karrman E, Johansson M, 2017. Source separation: Challenges & opportunities for transition in the swedish wastewater sector. Resources Conservation And Recycling 120, 144–156. https://doi.org/10.1016/j.resconrec.2016.12.004	Structure, Coordination, Interactions and networks, Capabilities, Directionality, Reflexivity, Values	Structure
16	Melia et al. 2017	Melia, P.M., Cundy, A.B., Sohi, S.P., Hooda, P.S., Busquets, R., 2017. Trends in the recovery of phosphorus in bioavailable forms from wastewater. Chemosphere 186, 381–395. https://doi.org/10.1016/j.chemosphere.2017.07.089	Structure	

17	Nättorp et al. 2017	Nättorp, A., Remmen, K., Remy, C., 2017. Cost assessment of different routes for phosphorus recovery from wastewater using data from pilot and production plants. Water Science and Technology 76, 413–424. https://doi.org/10.2166/wst.2017.212	Structure	
18	Nättorp et al. 2018	Nättorp, A., Kabbe, C., Matsubae, K., Ohtake, H., 2018. Development of phosphorus recycling in Europe and Japan, in: Phosphorus Recovery and Recycling. pp. 3–27. https://doi.org/10.1007/978-981-10-8031-9_1	Directionality	Structure, Directionality
19	Oster et al. 2018	Oster M, Reyer H, Ball E, Fornara D, McKillen J, Sorensen KU, Poulsen HD, Andersson K, Ddiba D, Rosemarin A, Arata L, Sckokai P, Magowan E, Wimmers K, 2018. Bridging Gaps in the Agricultural Phosphorus Cycle from an Animal Husbandry Perspective: The Case of Pigs and Poultry. Sustainability 10. https://doi.org/10.3390/su10061825	Structure, Capabilities	
20	Särkilahti et al. 2017	Särkilahti M, Kinnunen V, Kettunen R, Jokinen A, Rintala J, 2017. Replacing centralised waste and sanitation infrastructure with local treatment and nutrient recycling: Expert opinions in the context of urban planning. Technological Forecasting And Social Change 118, 195–204. https://doi.org/10.1016/j.techfore.2017.02.020	Structure, Coordination	
21	Ulrich 2019	Ulrich, A.E., 2019. Cadmium governance in Europe's phosphate fertilizers: Not so fast? Science of The Total Environment 650, 541–545. https://doi.org/10.1016/j.scitotenv.2018.09.014	Structure, Coordination, Directionality	
22	Withers et al. 2018	Withers PJA, Doody DG, Sylvester-Bradley R, 2018. Achieving Sustainable Phosphorus Use in Food Systems through Circularisation. Sustainability 10. https://doi.org/10.3390/su10061804	Structure, Directionality	Directionality

In addition, we have analysed data from 10 key-informant interviews. For each of our 8 analytical dimensions, we summarised the key barriers and opportunities below, including examples and quotes from the interviews and included articles (see **Figure 1** for the overview of results).

Figure 1 A brief summary of the findings across eight analytical dimensions.



2.5.1 Structure

This analytical dimension focused on barriers and opportunities of existing institutional infrastructure (e.g. regulations, legislation, standards) affecting innovation activities. Below we list main barriers and opportunities identified from the literature and interviews.

Barriers

The main barriers for innovative eco-technologies identified were connected to lack of end-of-waste criteria, administrative hurdles connected to EU fertilizer regulation and Registration, Evaluation, Authorization and Restriction on Chemicals (REACH), and limits to markets for reuse products.

- **Many reuse products are classified as waste and lack end-of-waste criteria**

According to the EU Waste directive[2], products classified as waste cannot be transported cross-borders, which hinders business (Ehlert and Schoumans, 2015).

- Bio-wastes, biochars, ashes and sewage sludge are considered waste, regardless of the quality (Ehlert and Schoumans, 2015); Interview 008)
- Most waste water treatment plants are classified as waste management and thus have to follow far stricter rules than fertilizer companies using phosphate rock. To gain a status of fertilizer producer, extra permits and new installations are needed for waste water treatment plants, which costs extra time and money.

[2] Directive 2008/98/EC sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products.

- Under the Waste Framework Directive, the European Commission has formulated end-of-waste criteria that lift the waste status of certain products, but there is a lack of criteria for many reuse products.
  - In general, the Waste Framework Directive does not acknowledge preparations for reuse, recycling, recovery or disposal as conditions that lift the waste status. For example, anaerobic digestion or composting are not yet designated as recycling methods that lift the status of waste (Ehlert and Schoumans, 2015).
  - There is a lack of end-of-waste criteria for materials of processed animal manure and/or bio-wastes. End-of-waste criteria for struvite (magnesium ammonium phosphate), ammonium sulphate from digestion processes, biochar and ashes are currently being formulated (Ehlert and Schoumans, 2015).
  - End-of-waste criteria have been formulated for compost and digestate but have not yet been implemented in EU regulations (e.g. on the trade of fertilizing materials) (Ehlert and Schoumans, 2015).

- **Administrative and legal hurdles related to EU fertilizer regulation**

The EU Fertilizers Regulation[3] sets requirements on fertilizers (e.g. regarding environmental and human health impacts). If fertilizers meet all requirements, they can be labeled as EC fertilizers. This improves a fertilizer's marketing position drastically since only labelled fertilizers can be traded freely in the EU (de Boer et al., 2018; Ehlert and Schoumans, 2015).

- The EU fertilizer regulation is focused on regulating chemical fertilizers and has not yet been adapted to innovative processing techniques for nutrient recovery (Ehlert and Schoumans, 2015).
  - Reuse products are often more variable in their composition and production processes, which would require more flexible regulations (Ehlert and Schoumans, 2015).
  - The EC label requires highly concentrated products, and fertilizing materials recovered from renewable resources quite often cannot meet the minimum requirements (Ehlert and Schoumans, 2015).
  - The Fertilizers Regulation is focused on the source of materials used for fertilizers instead of on the final fertilizer product (de Boer et al. 2018). For example, most digestate-derived products are not classified in any way, despite their characteristics being similar to those of commercial fertilizers (Bolzonella D et al., 2018).
  - Nutrients of animal or vegetable origin may not be added to fertilizers (Ehlert and Schoumans, 2015).
- Registering a new fertilizer type can take up to 7 years, which blocks innovation. Waste water treatment plants often choose to sell the recovered P as waste, instead of turning it into fertilizers (de Boer et al., 2018).
- Regulations on pollutants and nutrient load tend to favour chemical fertilizers
  - Fertilizer regulations consider heavy metal content in the final product, but not other elements, which are measurable in high concentrations such as

[3] Regulation (EC) No 2003/2003 related to fertilizers regulates the chemical compounds that provide nutrients to plants and ensures that technical requirements are implemented uniformly throughout the EU.

e.g., Cu or Zn (potentially toxic dependent on the dose). For e.g. sewage sludge ash, this is a disadvantage (Egle et al., 2015).

- There are no regulations on pollutant concentrations at the European level, again imposing a barrier for the EC fertilizer label (although this is about to change, see below under “Opportunities”) (de Boer et al., 2018).
- Application of animal manure (including products derived from manure) is strictly regulated in the Nitrates directive, but chemical fertilizers are not (Ehlert and Schoumans, 2015; Oster M et al., 2018).

- **Administrative hurdles related to REACH**

Fulfilling the requirements of REACH is an administrative process for which manufacturers and importers of recycled nutrient products are currently not well organized (de Boer et al., 2018; Ehlert and Schoumans, 2015).

- **Some reuse products are not allowed in organic farming**

EU regulations forbid the use of human excreta in organic farming which limits markets for reuse products (Fam et al., 2010; Fam and Mitchell, 2013; McConville et al., 2017a).

- **There is a lack of subsidies, and hence incentives, for P reuse**
  - To enable recovered P products to substitute and compete with primary fertilizers could require subsidisation or regulatory forcing to ensure that widespread agricultural adoption is economically feasible (Melia et al., 2017; Nättorp et al., 2018).

Opportunities

The main opportunities identified are connected to revision of regulations.

- **Revision of the EU fertilizer regulation is expected to improve market prospects for P reuse products**

As part of the EU’s Circular Economy Package, the EU institutions reached a preliminary agreement in November 2018 on new EU rules on fertilizers, which are expected to facilitate the access of organic and waste-based fertilizers to the EU Single Market. It will also introduce limits for cadmium and other contaminants in phosphate fertilizers (Europees Parlement, 2018):

  - Digestates, compost, food industry by-products, and animal by-products will be recognized categories according to the new rules. If products fulfil outlined criteria, they have product status and thus are no longer considered waste. This removes an important legal hurdle and facilitates marketing. Additional categories are in the process of being defined so they can be added (struvite, biochar, and ash) (Nättorp et al., 2018).

- **Novel P reuse technologies have an advantage in countries where agricultural reuse of sewage sludge is prohibited**

A combined drive for increased P reuse and a ban on sludge application on agricultural land increases the demand for alternative P recovery technologies ((Egle et al., 2016); Interview 001).

2.5.2 Coordination

This analytical dimension is defined as the organization between several components of a system that enables these to work effectively together across geographic scales, regime levels, and organizational hierarchies. Below we list main barriers identified from the literature and interviews. Opportunities were not identified within this category.

Barriers

The main barriers coordination included silo-thinking present at different scales, lack of harmonisation between policies within the EU and national levels, and complexity of actors in the policy landscape.

- **Silo thinking and unclear division of responsibilities at different scales**

Reuse of P requires integrated solutions across sectors such as sanitation, agriculture and forestry. Current siloed governance systems represent a barrier for such integrated solutions (Cordell et al., 2009; McConville et al., 2017a).

  - Globally, solutions for P scarcity problem are located partly in sanitation and partly in the agricultural sector, which requires integrated solutions and coordination across sectors (Cordell et al., 2009)
  - In Finland, agricultural advisors are specialised in specific domains of the farming system (e.g livestock feeding) and provide uncoordinated advice without holistic view of the farming system (Interview 009)
  - Agriculture, forestry and wastewater sectors are not cooperating in Finland, nor in other countries (Interview 010)
  - In Sweden, separation of legal responsibilities in the source-separation chain makes organization of the service chain difficult where source separated fractions are classified as household waste and thus separated from the municipal wastewater department. Municipal actors experience unclear division of responsibility and coordination difficulties (McConville et al., 2017b).

- **Lack of harmonized policies within the EU**

Conforming to all regulations in all countries is extremely difficult, costly and time-consuming for producers of reuse products (de Boer et al., 2018), and conflicting regulations often go against principles of circular economy (Interview 009):

  - National end-of-waste legislation
    - Linked to the problem of lacking EU criteria on end-of-waste status for reuse products (for further detail, see “Structure” above), some EU countries have national end-of-waste legislations that have not been harmonized (Ehlert and Schoumans, 2015), which costs time and money for producers of reused material to comply with (Hukari et al., 2016).
  - Recycled fertilizers
    - Linked to the problem of lacking EU regulations on organic fertilizers and their pollutant concentrations (for further detail, see “Structure” above), some countries pay special attention to recycled fertilizers, and other countries have more rigid regulations on pollutant concentrations such as heavy metals, which can have a negative effect on certain reuse products (e.g. struvite) (de Boer et al., 2018).

- Sludge[4]
  - Interviewees point out the need to harmonize the EU's sludge regulations (Interview 001, 008), which have not been updated since the Sewage sludge directive was introduced 1986, despite several attempts (Interview 008).
- Wastewater reuse without common standards
  - At the EU level, no common standards or quality guidelines for wastewater reuse have been implemented yet. Instead, member states are expected to adopt the requirements of various EU directives correlated with water reuse applications due to health and environmental concerns. No EU directives are "[…]directed at regulating or supporting water reuse as such" (Water Framework Directive, Waste Water Treatment Directive, Urban Waste Water Treatment directive, Groundwater Directive, Drinking Water Directive, Sewage Sludge Directive, Nitrates Directive, Thematic Strategy for Soil Protection, Bathing Water Directive, Freshwater Fish Directive, Habitats Directive, Industrial Emissions Directive) (Maass O and Grundmann P, 2018).

- **Goal conflicts in agricultural policies and subsidies**

Interviewees identify conflicting policies and subsidies in Finland and the EU in general, where farmers can e.g. both get subsidies for dealing with the problem of nutrient leaching, and at the same time receive subsidies for building a cattle house in an area where it is not possible to use the nutrients in a sustainable way (and hence increase the nutrient problem). In addition, most agricultural policies "are supporting farmers to be more competitive, increase farm size and make it more efficient. Sometimes this goes against the goals of a circular nutrient economy." (Interview 009)

- **Complex reuse policy landscape with heterogenous actors and multiple legal requirements**

Reuse actors have to comply with a whole range of policies, e.g. the Nitrates Directive, REACH, Fertilizer Regulation, Animal By-Products Regulations, and the Waste Framework Directive (among others) (Ehlert and Schoumans, 2015). At the same time, P recovery and recycling actors are a heterogeneous group that may be challenging to regulate effectively (Hukari et al., 2016).

2.5.3 Interactions and networks

This analytical dimension included interactions between actors with different roles and positions. Under interactions we included the exchange of knowledge, ideas, information and other resources. Below we list a barrier identified from the literature and interviews. Opportunities were not identified within this category.

Barriers

The barrier identified under this analytical dimension relates to chemical fertiliser lobby.

[4] The Sewage Sludge Directive 86/278/EEC seeks to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man. To this end, it prohibits the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil. Treated sludge is defined as having undergone "*biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use*" (*Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture*, 1986)

- **The chemical fertilizer lobby is well-organised and influential**

This influence is especially evident in the case of EUs new fertilizer regulation that is currently underway and was agreed to by the Trilogue in November 2018, regulations that are key for reuse fertilizer to enter the market, but which have been heavily delayed and do not include stringent reductions in fertilizer cadmium content over time (Europees Parlement, 2018; Gilbert, 2018). The fertilizer industry is acknowledged to have contributed to delaying the process and pushing for slack regulations on the cadmium content (de Rider et al., 2012), Interview 002, Interview 008).

2.5.4 Capabilities

This analytical dimension included competencies, knowledge and resources that enable actors in a system and built capacity to adapt to new and changing circumstances and (technological) opportunities. Barriers identified from the literature and interviews are listed below. Opportunities were not identified within this category.

Barriers
The main barriers were connected to limited knowledge about reuse eco-technologies and difficulties in cross-sectoral collaboration.

- Limited knowledge of the potential of several novel technologies for reuse

There is for instance limited knowledge on certain new technologies for manure processing (Oster M et al., 2018). McConville (2017b) reports that there is in some cases weak knowledge development in connection to innovations in source separation, which means that source-separation systems are often regarded as immature and risky by decision-makers.

- Farmers seeking cross-sectoral collaboration and working in systemic issues are experiencing difficulties to access funding

Interviews show that for instance the Rural development programme in Finland targets farmers and does not necessarily support cross-sectoral collaborations, e.g. for farmers collaborating with a biogas company. Other funding opportunities focused on industry do not fund agricultural activities (Interview 009).

- Limited local capacity for implementing reuse solutions

Swedish and Finnish actors report that there is limited capacity at the local level to implement and support reuse solutions.

  - "Municipal politicians [in Finland] don't know much about [manure and nutrient recycling] and they should get more information and education on these aspects." (Interview 011).
  - Swedish municipalities lack experience in dealing with source separated toilet fractions, and the application of the Swedish National Environmental Code on these fractions is rather untested (McConville et al., 2017a).

2.5.5 Directionality

Directionality is defined as a system's capacity to guide the direction of change, including formulating a shared long-term vision and signalling and communicating this vision. Barriers and opportunities identified from the literature and interviews are listed below.

Barriers

The main barriers related to the lack of clarity on P recovery and reuse in national legislations.

- **Lack of clarity and direction in national legislations, which hampers development and adoption of innovations for P reuse**

Only a few countries, such as Germany, have set out a clear, long-term strategy for how to deal with sewage sludge and P recovery. Countries such as Denmark and Sweden have set more general targets for recycling of P in sludge and other wastes (Nättorp et al., 2018).

  - Companies need to be able to predict the market and calculate risk. Lack of long-term policies hampers technology development and commercialization (Interview 001).
  - Swedish sludge legislation is perceived as outdated. Swedish farmers require much higher quality standards for the sludge than the legislation requires (Interview 008).
  - At a national level Swedish legislation supports the idea of nutrient reuse, including in the Environmental Code, dating from 1998, contains several objectives for recycling and efficient use of natural resources. However, there is currently no national target for nutrient recirculation. Such goals are needed to support the establishment of e.g. new source-separating systems, and to provide a standard for various solutions to bench-mark themselves against (McConville et al., 2017a).

- **'Circular economy' concept is gaining attention at EU level but needs to be translated into national policies and actions**

Interviewees report that while the circular economy concept is influential, e.g. as expressed in EU's Circular Economy Action Plan, it remains to be picked up and translated into national- and local-level policy and action.

  - "Circular economy as a concept is not present in the policy dialogue in Sweden. All policies today are linear. Resource reuse is currently more expensive." (Interview 001)
  - "In Finland, a circular economy model exists, but there is no common clear vision on how to achieve it" (Interview 009)
  - "Even though there is national-level awareness [in Finland], municipal politicians don't know much about [manure and nutrient recycling] and they should get more information and education on these aspects." (Interview 011)

- **Low political support for nutrient recycling, with the exception of P**

According to a study by McConville et al. (2017a) experts at the Swedish EPA and Swedish Agency for Marine and Water Management experience low political support for nutrient recycling, perhaps with the exception of P recycling.

- **There has historically been a low global awareness of the P issue, although this is gradually changing**

P was long lacking in global food and agriculture policy debates. The issue of peak P gained attention around a decade ago, and the focus has since broadened to the wider meaning of phosphate stewardship.

  - Global phosphate scarcity was for a long time missing from the dominant debates on global food security and environmental change (e.g. no mention P scarcity in the UN's Food and Agricultural Organization, the International Food Policy Research

Institute, the Millennium Ecosystem Assessment, the Global Environmental Change and Food Systems programme, the International Assessment of Agricultural Knowledge, etc.) (Cordell et al., 2009).
    - After much attention was paid to the issue of the continued long-term supply of phosphate rock during the past decade the focus has since broadened to the wider meaning of phosphate stewardship, including environmental, health, and quality considerations (Ulrich, 2019).

- **Current legislation on P is mainly designed to deal with eutrophication, not reuse**

Most legislation relating to the management of P (e.g. the current requirement in Europe to remove P from effluent water) is associated with reducing with the flow of P into water bodies to prevent eutrophication, and the legislation does little to encourage the recovery of P in a form suitable for use as an agricultural fertilizer (Dawson and Hilton, 2011).

- **Risk of new P policies steering in the wrong direction**

There is a fear among certain actors that too narrow policies on P recovery may lead to lock-in into sub-optimal technologies that have a high climate impact, does not reuse other nutrients and/or carbon, and disincentivizes upstream work to create clean sludge.
    - *"The worst-case scenario for new Swedish investigation and legislation would be that only incineration is allowed and that only soil for agricultural use receives standards but not soil for planting. That would mean that incentives go to using sludge for soil for planting, which is a huge waste of resources since only the carbon is reused but not the nutrients. The Swedish investigation is inspired by Germany, but Germany is different than Sweden. Germany already has 60% incineration, they do not do any upstream work, and the main (polluting) industries are largely in the big cities. In Germany, waste water treatment plants that connect less than 50.000 people (which corresponds to 25% of Germany's population) are excepted from the new legislation."* (Interview 008)
    - *" In Germany there are water associations that operate a large number of waste water treatment plants. They all use mono-incineration since their main goal is to become independent from any external incineration. So they build their own incineration plant. They don't worry about energy recovery. And they postpone the P problem into the future, since mono-incineration plants store ashes, but there is no economically feasible technology on the market to recover P from the ashes*." (Interview 006)

Opportunities

- The opportunity identified was about observed increased interest in reuse of P at the policy level in the EU. **Increased policy attention towards P reuse**

Nättorp et al. (2018) list several opportunities influencing P recycling in Europe, in particular:
    - P is recognized to be of critical importance and is now placed on the EU's list of critical raw materials (2014)
    - Technical recovery of P has been recently made obligatory in two EU countries (Switzerland and Germany).
    - The circular economy package launched by the European Commission in 2015 targets the areas of product design, production processes, consumption, secondary raw materials, and innovation investment. It is an important signal that Europe sees circular economy as a key to prosperity and a potential solution to many resource-related problems such as resource scarcity, resource criticality, and emissions.

- As part of the Circular Economy Package, the EU is revising its fertilizer regulations (see "Structure" above), which is expected to drive technical P recycling and recycling of organic P materials (Nättorp et al., 2018) and create new business opportunities for the fertilizer industry in the marketing of secondary P (Withers et al., 2018).

2.5.6 Articulation

This analytical dimension is about system capacity to anticipate users' needs, integrate, and act upon these. Barriers identified from the literature and interviews are listed below. Opportunities were not identified within this category.

Barriers
Identified barriers concern usability of products from reused P.

- **Products from wastewater treatment plants do often not meet needs of farmers and fertilizer industry**

Because of the historical policy focus on eutrophication (for further detail, see "*Directionality*" above), the P-rich products derived from waste water streams do often not meet the demand from farmers:

- *"Policies for cleaning point sources have achieved good results particularly to reduce phosphate in waste water treatment, but the iron-phosphate rock produced by sludge is not easily absorbed by plants. So, the current system of cleaning water in treatment plants is not built with reuse in mind." (Interview 002)*

- **Need for better evidence to increase farmer acceptance, and to allow farmers to choose technology**

To increase uptake of reuse practices and technologies, there is a need for supporting evidence across different farm types and contexts. There is also a need to allow for a diversity of approaches, enabling farmers to choose a technology that fits their particular needs:

- "*It is difficult to just introduce new technologies to farmers, without having good evidence so that it is acceptable to farmers and work in local conditions (e.g. with a particular soil type). Very often, one single technology is dominant. The [Finnish] Ministry [of Agriculture] is often recommending just one. Farmers should be able to select which one is.*" (*Interview 010).*

2.5.7 Reflexivity

This analytical dimension relates to the capacity to monitor, learn and act upon knowledge, It includes creating a space for experimentation and learning, whilst allowing a diversity of options for dealing with uncertainty. Barriers identified from the literature and interviews are listed below. Opportunities were not identified within this category.

Barriers
The main barriers identified relate to sectoral narrow-mindless and inability to change.

- **Wastewater sector is conservative and difficult to change**

The waste water and sanitation sector are identified to be resistant to change, which creates a barrier for innovative technologies. Fam and Mitchel (2013) note that this is in part due to embedded social behaviours, habits and practices. This is also visible from our interviews:

- *"The waste water sector is very conservative, they are hesitant to try new technologies. Traditionally, they look to the neighbouring waste water treatment plants. They prefer small, incremental improvements, they are not open to fundamental changes in treatment. They fulfil legal requirements – if they comply, they do no more."(Interview 006).*

- **In national agricultural policy, there is often a narrow-minded focus on a single technology**

Interviews reveal that there might be a tendency to focus on single technologies in agriculture, which restricts opportunities to experiment with a diversity of alternative technologies and practices. There is also a reported lack of experience-sharing across countries:

- *"Very often, one single technology is dominant. The [Finnish] Ministry [of Agriculture] is often recommending just one. Farmers should be able to select which one is. Calcium sulphate is now number one. There is little discussion about the limitations about this technology. Climate change is also important." (Interview 010).*
- *"Many countries have a tradition or one dominant technology and do not take examples from other countries. For example, structural liming for reducing P loading is dominant in Sweden. For agriculture, it is difficult to learn from other countries, primarily due to mental barriers." (Interview 010).*

- **A narrow focus on incineration may close promising alternatives down**

Related to the previous point, interviewees point out that the current strong focus on sludge incineration in e.g. Germany (for more detail, see "Directionality" above) as a means to achieve P reuse gives preference to one single technology, which is perceived to limit the space for alternative technologies:

- *"It is very difficult to introduce sludge-derived fertilizers or soil enhancers in legislation. Everything is moving in the opposite direction. No one wants to apply sludge on their fields anymore, people will be reluctant to again allow anything derived from sludge to be used in fields. P recovery is the one exception, where P recovered from sludge is allowed on fields. The coming EU fertilizer law will allow recovered P to be used as fertilizer at EU level – but only P, not ashes, coal etc. Most countries in Europe are moving towards incineration" (Interview 006).*

2.5.8 Values

This analytical dimension included 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. Barriers identified from the literature and interviews are listed below. Opportunities were not identified within this category.

Barriers

The main barriers identified are connected to negative attitudes towards new technologies and lack of awareness of circular economy.

- **Entrenched linear ways of thinking and lack of awareness of circular economy in society**

One Swedish actor who promotes circular economy solutions identifies a lack of awareness in circular economy approaches, and entrenched linear mindsets:

- *"Attitudes at Swedish and EU level are critical. At the moment, there is no awareness of circular economy approaches. There are underlying principles and mental models in society, such as the waste management hierarchy – this should instead be seen as a resource hierarchy i.e. a more circular model." (Interview 001).*

- **Fear of consumer attitudes towards sludge, but lack of actual data**

Food industry actors claim negative consumer attitudes towards the use of sewage sludge on agricultural land, although there is a lack of knowledge on the topic:

- *"To the best of my knowledge, there are no studies on consumer attitudes when it comes to P reuse. […] Several Swedish food companies fear consumer backlash and have decided to not use products that have applied sludge on fields." (Interview 008).*

- **Scepticism around the safety of water reuse practices in Europe**

The lack of common criteria at the EU level for managing health and environmental risks related to water reuse (for more detail, see Coordination) is a cause of mistrust in the safety of water reuse practices and thus, one of the main obstacles for water reuse in Europe. The EU Commission is currently preparing to propose minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge. However, the proposed requirements are still under review (Maass O and Grundmann P, 2018).

- **Psychological barrier against productive use of human excreta**

Cordell et al. (2011, 2009) find that farmers may be reluctant to use wastes because of cultural barriers and perceived or real contamination concerns, and that sanitation professionals and society at large are stuck in a flush-and-discharge mentality that inhibits the productive use of human excreta.

- **Centralization paradigm dominates**

Cordell et al (2011) find that the common belief that centralised systems are superior is a dominant paradigm underlying current thinking about sanitation and waste water.

- **Focus on technological fixes rather than systemic change**
  - One interviewee points out that there is a narrow focus on technological fixes rather than more integrated, systemic solutions that address the root cause of the problem. For instance, in Finland and many European countries, animal farms (which produce large amounts of nutrient-rich manure) are located in different parts of the country than crop farms (which demand nutrients), which creates nutrient imbalances across the country: *"It is important to remember that technology cannot solve all problems. In Finland the main problem is the structure of agriculture. Nutrients are concentrated in areas with high livestock production – to some extent technologies can be introduced to enable transportation to crop farms. But it would be better to make a more systemic change, that would change the structure of the agricultural system. As long as we consume livestock products, the livestock production should be distributed more evenly in the country."(Interview 009).*

Box 1 shows identified barriers and opportunities in connection to source separation technology.

BOX 1. BARRIERS AND OPPORTUNITIES FOR SOURCE-SEPARATION

Source separation of wastewater flows typically involves separating blackwater (i.e. wastewater from toilets) and urine. Such technologies capture concentrated nutrient-rich waste which facilitates nutrient recovery and pollutant removal (Larsen et al., 2004, 2009 – cited in (McConville et al., 2017a)).

While many of the P recovery technologies studied in this report can be seen as incremental improvements of the current waste water system – that is, they can (depending on the technology) fit quite well within current institutions, infrastructure and paradigms - source-separating systems on the other hand typically require more fundamental changes to the system. For instance, source-separating systems require new infrastructure, possibly a new paradigm (e.g. decentralization as opposed to centralization), and new institutional arrangements. In addition to the barriers and opportunities outlined elsewhere in this repost, we describe below some specific challenges and opportunities facing source-separation systems.

1. Structure

Barrier

- **Weak legislation for wastewater utilities that hampers source separation at the household level**

There is weak Swedish legislation for wastewater utilities to require source separation by the household, even if it would greatly simplify the provision of wastewater services (McConville et al., 2017a)

- **Swedish municipalities in a catch-22 situation due to mismatch between responsibility and mandate**

Related to the point above, there is a catch-22 situation in the Swedish regulation where on one hand Swedish municipalities cannot make demands, e.g. on source-separating systems, if there is no end-user for the collected nutrient-rich fractions, while on the other hand a farmer cannot legally be forced to use a specific product (e.g., source-separated urine). Municipalities are thus responsible for managing the waste, but do not have the mandate to control neither the production stage (household toilet), nor the recycling stage (farmer)
(McConville et al., 2017b)

- **Source separation requires entirely new infrastructures**

Current centralized infrastructure for waste water and sewage creates a lock-in. Alternative solutions such as source separation, which require other infrastructure, may only be feasible in niche environments and when planning new areas.

  - Systems for urine diversion face organizational difficulties including establishing logistical systems for e.g. collection and transport, in part rooted in a lack of guidelines, standards and norms for management of the TIS (Sweden)(McConville et al., 2017a)
  - The sanitation sector is a mature sector entrapped in path-dependent infrastructures and - although open to environmental monitoring and

processes to improve efficiency - is resistant and slow to change (Fam and Mitchell, 2013)
  - With well-established centralised systems, launching distributed alternatives is challenging (Särkilahti M et al., 2017).

Opportunity

- **The Swedish "plan monopoly" can be used to support source separation systems by driving changes in existing infrastructure**

The Planning and Building Act (2010) in Sweden gives municipalities the sovereign right to adopt land use plans (i.e. a so-called plan monopoly) and decide on the spatial planning and infrastructure development, which can be used to drive changes in infrastructure, e.g. for source separation. This is identified in the literature as an underused opportunity *(McConville et al., 2017b)*

2. Coordination

Barriers

- **Local interpretations of national environmental policy related to source separation are found to differ across several Swedish municipalities**

At the national level, Sweden has the Environmental Code and Environmental Quality Objectives as enabling policies for source separating systems. However, McConville et al. (2017a) found that there are no legal precedents available and the interpretation of the Code is hence up to the municipalities.

- **Recycling of urine has no institutional or organizational home**

Source-separation is currently no one's explicit responsibility, which means it is seen as peripheral by all stakeholders and sectors (such as water service providers, town planners and farmers) and is not perceived as important enough for any single stakeholder group to make it a priority (Cordell et al., 2009).

3. Interactions and networks

Barrier

- **Local politicians' support is important but not always present**

McConville et al. (2017a) found that support from local politicians and in local policy documents for source-separating systems is not always present, and seems to decline over time in municipalities where there are source-separating systems in place.

Opportunity

- **Available communication platforms exist but are underused**

According to McConville et al. (2017a), there are available communication platforms relevant for source-separating systems in Sweden, which could be more efficiently than at present.

4. Capabilities

Barrier

- **Alternative systems such as source separation require social capital**

In a Swedish context, McConville et al. (2017a) report how municipalities show difficulties in organizing the entire source-separating system from collection to reuse. Organizational difficulties are linked to weaknesses in the social relationships between e.g. municipalities, farmers, and financial actors.

- **Experience of limited public investment in alternative solutions in Sweden**

One interviewee noticed that there has been little funding available and little experimentation with alternative systems such as source-separation in Sweden:

  - "There has been quite little investment in P reuse, up until a few years back. In the last 3-4 years, there have been a few projects starting." (Interview 008)

5. Directionality

Opportunity

- **Baltic Sea Action Plan highlights the potential of source-separation**

The Baltic Sea Action Plan has highlighted the potential of urine diversion as a means of reducing the P and N discharge into the Baltic Sea (Swedish EPA 2009, referenced in (Fam et al., 2010))

6. Values

Barriers

- **Lack of social learning hinders source-separating systems**

In Sweden, establishing logistical systems for source-separating systems is found to be difficult due to lack of social learning that would support development of these new systems (McConville et al., 2017a).

- **For urine diversion systems, social behaviours, habits and practices are key**

Fam and Mitchell (2013) find that embedded social behaviours, habits and practices inhibits a shift to urine diversion systems in Sweden.

2.6 DISCUSSION

This study highlights that the regulatory system in the EU is largely geared towards the use of chemical fertilizers, which creates a whole range of legal and administrative hurdles for organic fertilizers and create unequal competition between chemical and reused P. The EU regulative framework is mainly focusing on the source of the fertilizer origin, the requirement on high P concentrations and low variations in the fertilizer composition, which reused fertilizer products often do not meet.

Reused P also faces challenges associated with waste regulations and end-of-waste criteria. The challenges of turning resource-rich "waste" into usable and legally acceptable products are an important hurdle for circular economy in general and can be seen as a legacy of the linear take-make-dispose thinking.

The circular economy concept is gaining traction at the EU level with the Circular Economy package. However, this report shows that important barriers remain for this vision to be realized. The centralization paradigm has been a strong driving force behind the current waste water system but might need to be challenged to open up for more decentralized solutions, such as source-separation. Silo-thinking is also a legacy of a linear production model and a barrier for the circular economy, since circular solutions will require increased collaboration and consideration of other sectors to ensure efficient reuse. For instance, waste water treatment plants will increasingly need to consider the needs of the agricultural sector. The heterogeneity of the reuse sector is another challenge, as both reused products and actors are often more heterogeneous than their conventional counterparts, which is challenging for regulators and innovators alike. Furthermore, as this study has revealed, the circular economy concept is prominent at the EU level but remains to be mainstreamed at local level and among the broader public.

Countries such as Germany are taking the lead in transitioning towards a more circular P economy. 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. While the sludge ban in Germany, and requirements on P recovery do indeed provide a clear direction for technology developers, it does in practice give preference to one single type of technology (i.e. mono-incineration), which risks crowding out other promising technologies and practices and may lead to a lock-in into a sub-optimal system. Apart from mono-incineration there are other integrated and systemic solutions available, such as agroecological symbiosis, source-separating systems and clean sludge.

Values and perceptions towards recovered and reused P are not well understood. There seems to be a lack of awareness of P and its uses, and generally lack of knowledge of the circular economy in society. In the agricultural sector, perceptions on the use of recovered and reused P vary. Generally, farmers want more evidence of viable technologies that can safely produce pure P without increasing production costs (see *Articulation*) before committing to a new system of production.

2.6.1 Limitations

The study attempted to develop and apply framework to locate a comprehensive set of barriers and opportunities for reuse technologies in the Baltic Sea region. To do this, eight analytical dimensions (structure, coordination, interactions, capabilities, directionality, reflexivity, articulation, and values) were adapted (Weber and Rohracher, 2012) and used for the analysis. This approach allowed for a very detailed analysis of policy-related barriers and opportunities. Nevertheless, the categories are not mutually exclusive and there are conceptual overlaps between them (e.g. a structural policy barrier might also involve lack of coordination). Moreover, analysis of market-related barrier and opportunities for technological innovation would benefit this study and this is planned for future research and it is being partly addressed in a related BONUS RETURN report (see (Carolus, 2018)).

This study included a relatively limited literature sample. We searched for literature published in English and we have focused on the Baltic Sea region. Nevertheless, non-English literature with wider geographical scope might include relevant insights for this report. However, we have also included key-informant interviews to supplement our literature review.

Additionally, we have focused on P reuse solely, but identifying barriers and limitations for reuse of other nutrients including carbon, nitrogen, reuse of energy and water is equally important for devising policy recommendations in the light of circular economy. Furthermore, whilst this study has focused on P reuse, we acknowledge that there is a need to reduce demand for P altogether, across all stages of the production chain: from P mining to use of P as a fertilizer in agriculture (e.g. reducing waste from mining and fertilizer production, limiting the application of P on agricultural land, reducing food waste, and similar).

2.7 CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this report and taking into account the stated limitations of this study, we argue that there is a need to increase policy steering towards P reuse, without closing promising systemic solutions. To achieve this, we elaborate below on several recommendations for policy and future research in agriculture and waste water sectors of countries in the Baltic Sea region.

Mainstreaming the idea of circular economy across society and local, national and supranational governance structures is a priority. This will require 1) shift in mindsets (away from take-make-dispose and towards reduce-reuse-recycle-recover strategy), 2) new circular business models and 3) increasing implementation capacity of national and local governments and municipalities.

Continuing efforts to simplify the legal framework for reused P products, particularly at EU level is necessary. In addition, a fair P price which includes aspects such as health and environmental impacts from P mining should be established (Mayer et al., 2016).

Sustainable solutions are today an option rather than an obligation in public procurement. Sustainable solutions that ensure circularity could be more actively implemented when municipalities buy products and services from entrepreneurs. However, few cities have the knowledge and capacity necessary to procure for complex cross-cutting problems and procurement rules could be more prescriptive than they are today.

Technologies for P reuse are necessary and viable in larger cities, where the tax-payer base is large. However, smaller cities pollute disproportionate to their population because technologies for P reuse can be too costly. Here, ensuring more sustainable practices in farms, or establishing adequate decentralized systems will continue to be important.

Testbeds for innovations in municipalities should favour circular solutions with multiple benefits to society and minimized effects upon the environment. Municipalities can create clearer guidelines and requirements that send strong signals to entrepreneurs on the type of technologies desired for the development of the city, while at the same time making it easier for circular innovations to succeed.

Alternative solutions such as source separation (see **Box 1**), which help recovery of multiple resources (nutrients, water, energy) could be more widely implemented. Nevertheless, this would require investment in different infrastructure and a long-term policy commitment. This could be feasible in newly-developed housing projects (such as H+ in Helsingborg; see https://hplus.helsingborg.sev).

Promotion of new business models with increased collaboration between waste water treatment plants (i.e. a source of reused P), fertilizer companies (i.e. a potential client for reused P), and farmers (i.e. potential end-users of recycled P) is a necessity for circular P economy.

Changing farm structures that allow for more efficient use of manure in agriculture should be investigated (Svanbäck and McCrackin, 2018). At present, large specialized farms are favoured by the EU's Common Agricultural Policy (Guiomar et al., 2018), but better understanding of the role that small or medium farms could play for reuse of P sources is necessary.

Relatedly, a comprehensive assessment of agricultural practices with focus on how P is currently used (and abused) in food systems is needed as it can contribute to establishing a system where lower use of nutrients is favoured (e.g. through tax, or incentives).

2.8 REFERENCES

Barquet, K., 2018. Climate Change, Transitions, And Geopolitics, in: Raisina Files: Debating Disruption in the World Order. Observer Research Foundation 2018, New Delhi.

Bolzonella D, Fatone F, Gottardo M, Frison N, 2018. Nutrients recovery from anaerobic digestate of agro-waste: Techno-economic assessment of full scale applications. Journal Of Environmental Management 216, 111–119. https://doi.org/10.1016/j.jenvman.2017.08.026

Carolus, J., 2018. D.2.4 – State of the art report on economic models in BSR. BONUS RETURN Deliverables.

Cooper, J., Lombardi, R., Boardman, D., Carliell-Marquet, C., 2011. The future distribution and production of global phosphate rock reserves. Resources, Conservation and Recycling 57, 78–86. https://doi.org/10.1016/j.resconrec.2011.09.009

Cordell, D., Drangert, J.-O., White, S., 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change 19, 292–305. https://doi.org/10.1016/j.gloenvcha.2008.10.009

Cordell, D., Rosemarin, A., Schröder, J.J., Smit, A.L., 2011. Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. Chemosphere 84, 747–758. https://doi.org/10.1016/j.chemosphere.2011.02.032

Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture, 1986. , Official Journal L.

Dawson, C.J., Hilton, J., 2011. Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. Food Policy 36, S14–S22. https://doi.org/10.1016/j.foodpol.2010.11.012

de Boer, M., Romeo-Hall, A., Rooimans, T., Slootweg, J., 2018. An Assessment of the Drivers and Barriers for the Deployment of Urban Phosphorus Recovery Technologies: A Case Study of The Netherlands. Sustainability 10. https://doi.org/10.3390/su10061790

de Rider, M., de Jong, S., Polchar, J., Lingemann, S., 2012. Risks and Opportunities in the Global Phosphate Rock Market.

Derricott, A., 2018. Global fertilizer prices hang on cost of China's greener future [WWW Document]. URL https://www.crugroup.com/knowledge-and-insights/insights/2018/global-fertilizer-prices-hang-on-cost-of-china-s-greener-future/

Egle, L., Rechberger, H., Krampe, J., Zessner, M., 2016. Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies. Science of The Total Environment 571, 522–542. https://doi.org/10.1016/j.scitotenv.2016.07.019

Egle, L., Rechberger, H., Zessner, M., 2015. Overview and description of technologies for recovering phosphorus from municipal wastewater. Resources Conservation And Recycling 105, 325–346. https://doi.org/10.1016/j.resconrec.2015.09.016

Ehlert, P.A.., Schoumans, O.F., 2015. Products, by-products and recovered secondary materials from processed animal manure. Wageningen Alterra 30.

Engström, A., Michaëlsson, K., Suwazono, Y., Wolk, A., Vahter, M., Åkesson, A., 2011. Long-term cadmium exposure and the association with bone mineral density and fractures in a population-based study among women. Journal of Bone and Mineral Research 26, 486–495. https://doi.org/10.1002/jbmr.224

Europees Parlement, 2018. Fertilisers/cadmium: Parliament and Council negotiators reach provisional deal. Press Release.

Fam, D., Mitchell, C., Abeysuria, K., 2010. Institutional Challenges to System Innovation in Wastewater Management – The Case of Urine Diversion in Sweden. Proceedings of the Water Environment Federation 2010, 871–888. https://doi.org/10.2175/193864710798284706

Fam, D.M., Mitchell, C.A., 2013. Sustainable innovation in wastewater management: lessons for nutrient recovery and reuse. Local Environment 18, 769–780. https://doi.org/10.1080/13549839.2012.716408

Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions 1, 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Gilbert, N., 2018. European Union debates controversial plans to limit cadmium in fertilizer. Science. https://doi.org/10.1126/science.aat8448

Gobler, C.J., Doherty, O.M., Hattenrath-Lehmann, T.K., Griffith, A.W., Kang, Y., Litaker, R.W., 2017. Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. Proceedings of the National Academy of Sciences 114, 4975–4980. https://doi.org/10.1073/pnas.1619575114

Guinder, V., Molinero, J., 2013. Climate Change Effects on Marine Phytoplankton, in: Menendez, M. (Ed.), Marine Ecology in a Changing World. CRC Press, pp. 68–90. https://doi.org/10.1201/b16334-4

Guiomar, N., Godinho, S., Pinto-Correia, T., Almeida, M., Bartolini, F., Bezák, P., Biró, M., Bjørkhaug, H., Bojnec, Š., Brunori, G., Corazzin, M., Czekaj, M., Davidova, S., Kania, J., Kristensen, S., Marraccini, E., Molnár, Z., Niedermayr, J., O'Rourke, E., Ortiz-Miranda, D., Redman, M., Sipiläinen, T., Sooväli-Sepping, H., Šūmane, S., Surová, D., Sutherland, L.A., Tcherkezova, E., Tisenkopfs, T., Tsiligiridis, T., Tudor, M.M., Wagner, K., Wästfelt, A., 2018. Typology and distribution of small farms in Europe: Towards a better picture. Land Use Policy 75, 784–798. https://doi.org/10.1016/j.landusepol.2018.04.012

Haddaway, N.R., Collins, A.M., Coughlin, D., Kirk, S., 2015. The Role of Google Scholar in Evidence Reviews and Its Applicability to Grey Literature Searching. PLOS ONE 10, e0138237. https://doi.org/10.1371/journal.pone.0138237

Hansson, M., Viktorsson, L., Andersson, L., 2018. Oxygen Survey in the Baltic Sea 2017 - Extent of Anoxia and Hypoxia, 1960-2017. Swedish Meteorological and Hydrological Agency (SMHI), Göteborg, Sweden.

Hénault, C., Grossel, A., Mary, B., Roussel, M., Léonard, J., 2012. Nitrous Oxide Emission by Agricultural Soils: A Review of Spatial and Temporal Variability for Mitigation. Pedosphere 22, 426–433. https://doi.org/10.1016/S1002-0160(12)60029-0

Hukari, S., Hermann, L., Nättorp, A., 2016. From wastewater to fertilisers — Technical overview and critical review of European legislation governing phosphorus recycling. Science of The Total Environment 542, 1127–1135. https://doi.org/10.1016/j.scitotenv.2015.09.064

Jokinen, S.A., Virtasalo, J.J., Jilbert, T., Kaiser, J., Dellwig, O., Arz, H.W., Hänninen, J., Arppe, L., Collander, M., Saarinen, T., 2018. A 1500-year multiproxy record of coastal hypoxia from the northern Baltic Sea indicates unprecedented deoxygenation over the 20th century. Biogeosciences 15, 3975–4001. https://doi.org/10.5194/bg-15-3975-2018

Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy – From review of theories and practices to development of implementation tools. Resources, Conservation and Recycling 135, 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Lawhon, M., Murphy, J.T., 2012. Socio-technical regimes and sustainability transitions: Insights from political ecology. Progress in Human Geography 36, 354–378. https://doi.org/10.1177/0309132511427960

Loorbach, D., Frantzeskaki, N., Avelino, F., 2017. Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annual Review of Environment and Resources 42, 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

Maass O, Grundmann P, 2018. Governing Transactions and Interdependences between Linked Value Chains in a Circular Economy: The Case of Wastewater Reuse in Braunschweig (Germany). Sustainability 10. https://doi.org/10.3390/su10041125

Mayer, B.K., Baker, L.A., Boyer, T.H., Drechsel, P., Gifford, M., Hanjra, M.A., Parameswaran, P., Stoltzfus, J., Westerhoff, P., Rittmann, B.E., 2016. Total Value of Phosphorus Recovery. Environmental Science & Technology 50, 6606–6620. https://doi.org/10.1021/acs.est.6b01239

McConville, J.R., Kvarnstrom, E., Jonsson, H., Kärrman, E., Johansson, M., 2017a. Source separation: Challenges & opportunities for transition in the swedish wastewater sector. Resources Conservation And Recycling 120, 144–156. https://doi.org/10.1016/j.resconrec.2016.12.004

McConville, J.R., Kvarnström, E., Jönsson, H., Kärrman, E., Johansson, M., 2017b. Is the Swedish wastewater sector ready for a transition to source separation? Desalination And Water Treatment 91, 320–328. https://doi.org/10.5004/dwt.2017.20881

Melia, P.M., Cundy, A.B., Sohi, S.P., Hooda, P.S., Busquets, R., 2017. Trends in the recovery of phosphorus in bioavailable forms from wastewater. Chemosphere 186, 381–395. https://doi.org/10.1016/j.chemosphere.2017.07.089

Nättorp, A., Kabbe, C., Matsubae, K., Ohtake, H., 2018. Development of phosphorus recycling in Europe and Japan, in: Phosphorus Recovery and Recycling. pp. 3–27. https://doi.org/10.1007/978-981-10-8031-9_1

Neset, T.-S.S., Cordell, D., 2012. Global phosphorus scarcity: identifying synergies for a sustainable future. Journal of the Science of Food and Agriculture 92, 2–6. https://doi.org/10.1002/jsfa.4650

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., Erasmi, S., 2016. Greenhouse gas emissions from soils—A review. Chemie der Erde - Geochemistry 76, 327–352. https://doi.org/10.1016/j.chemer.2016.04.002

O'Neil, J.M., Davis, T.W., Burford, M.A., Gobler, C.J., 2012. The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. Harmful Algae 14, 313–334. https://doi.org/10.1016/j.hal.2011.10.027

Oster M, Reyer H, Ball E, Fornara D, McKillen J, Sorensen KU, Poulsen HD, Andersson K, Ddiba D, Rosemarin A, Arata L, Sckokai P, Magowan E, Wimmers K, 2018. Bridging Gaps in the Agricultural Phosphorus Cycle from an Animal Husbandry Perspective: The Case of Pigs and Poultry. Sustainability 10. https://doi.org/10.3390/su10061825

Paerl, H.W., Huisman, J., 2008. CLIMATE: Blooms Like It Hot. Science 320, 57–58. https://doi.org/10.1126/science.1155398

Paerl, H.W., Paul, V.J., 2012. Climate change: Links to global expansion of harmful cyanobacteria. Water Research 46, 1349–1363. https://doi.org/10.1016/j.watres.2011.08.002

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M., Barau, A., 2017. Exploring the governance and politics of transformations towards sustainability. Environmental Innovation and Societal Transitions 24, 1–16. https://doi.org/10.1016/j.eist.2016.09.001

Powell, N., Osbeck, M., Larsen, R.K., Andersson, K., Schwartz, G., Davis, M., 2013. The Common Agricultural Policy Post-2013: Could Reforms Make Baltic Sea Region Farms More Sustainable?

Rosemarin, A., Schroder, J.J., Dagerskog, L., Cordell, D., Smit, A.L., 2011. Future supply of phosphorus in agriculture and the need to maximise efficiency of use and reuse. International Fertiliser Society. Proceedings 685, 1–28.

Ross, J.Z., Omelon, S., 2018. Canada: Playing catch-up on phosphorus policy. FACETS 3, 642–664. https://doi.org/10.1139/facets-2017-0105

Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. Foresight 3, 15–31. https://doi.org/10.1108/14636680110803003

Särkilahti M, Kinnunen V, Kettunen R, Jokinen A, Rintala J, 2017. Replacing centralised waste and sanitation infrastructure with local treatment and nutrient recycling: Expert opinions in the context of urban planning. TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE 118, 195–204. https://doi.org/10.1016/j.techfore.2017.02.020

Schröder, J.J., Smit, A.L., Cordell, D., Rosemarin, A., 2011. Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere 84, 822–831. https://doi.org/10.1016/j.chemosphere.2011.01.065

Smolders, E., Six, L., 2013. Revisiting and updating the effect of phosphate fertilizers to cadmium accumulation in European agricultural soils.

Svanbäck, A., McCrackin, M., 2018. How changes in farm structure could help reduce nutrient leakage to the Baltic Sea. Baltic Sea Centre, Stockholm University.

SYKE, 2018. Nutrient load into the Baltic Sea continues to be too high, and global warming also increases the risk of blue-green algae blooms [WWW Document]. URL https://www.ymparisto.fi/en-US/Waters/Nutrient_load_into_the_Baltic_Sea_contin(47430) (accessed 1.4.19).

Treib, O., Bähr, H., Falkner, G., 2007. Modes of governance: towards a conceptual clarification. Journal of European Public Policy 14, 1–20. https://doi.org/10.1080/135017606061071406

Ulrich, A.E., 2019. Cadmium governance in Europe’s phosphate fertilizers: Not so fast? Science of The Total Environment 650, 541–545. https://doi.org/10.1016/j.scitotenv.2018.09.014

Visser, P.M., Verspagen, J.M.H., Sandrini, G., Stal, L.J., Matthijs, H.C.P., Davis, T.W., Paerl, H.W., Huisman, J., 2016. How rising CO 2 and global warming may stimulate harmful cyanobacterial blooms. Harmful Algae 54, 145–159. https://doi.org/10.1016/j.hal.2015.12.006

Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Research Policy 41, 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015

Withers, P., Doody, D., Sylvester-Bradley, R., 2018. Achieving Sustainable Phosphorus Use in Food Systems through Circularisation. Sustainability 10. https://doi.org/10.3390/su10061804